The Interrelated Costs and Benefits Associated With Agricultural and Hydropower Water Use

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by

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AGRICULTURAL AND HYDROPOWER WATER USE - THE INTERRELATED EFFECTS

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INTRODUCTION

Among the many water uses in Montana, irrigation and hydropower are far and away the most important in terms of volume requirements. At many locations these two uses compete for the limited resource, and consequently, each is affected by the activities of the other. Water diverted for irrigation is in part consumed and thus not available for power production. Even the unconsumed portion of the irrigation diversion, the return flow, is delayed significantly and therefore temporarily unavailable for power generation. Power production, although not a consumer of water, does place a time demand on the resource in that water stored in reservoirs for power production is temporarily unavailable to irrigators.

In this competitive setting, any change in either user's activity almost invariably has an impact on the other user. Such changes are certain to occur in the future. For example, gradual and inevitable use changes will be associated with improving irrigation efficiencies. Efficiencies, which have been increasing with expanded sprinkler use and reduced conveyance loss, are projected to increase even more rapidly in the future (1). The increased water supply derived from such efficiency improvements might conceivably be used in a variety of ways and thus have a variety of impacts. However it is used, it will almost certainly have an impact on all users. If, for instance, it were used to irrigate additional lands, the same total diversion applied now to a larger area would yield a reduced return flow. The reduced return flow would negatively impact both downstream power producers and irrigators. In addition to these efficiency related changes in water use, other use changes are likely to be proposed (as they have been in the past) for a variety of reasons (economic, environmental, technological, etc.). These

proposed changes, whatever their nature, would almost certainly impact users to some degree.

There are costs and benefits, monetary and otherwise, that accrue to competing users from any water use or change in water use. Competing water users need to understand the interdependencies among competing uses so that they can anticipate the costs and benefits that will result from changes in use. Unfortunately, there is often a negative knee-jerk reaction to any proposed use or change in use by others. This sort of response may not be warranted since the proposed use or change in use may not be disadvantageous to competitive users. In fact a user may benefit from changes proposed by a competitive user. Power producers, for instance, may benefit from increases in upstream irrigation activity because irrigation diversions and the resultant delayed groundwater return flows smooth streamflow fluctuations. Thus during the winter, when power is generally at a premium, streamflows are maintained at artificially high levels by groundwater return flows from the irrigation activities of previous seasons. The groundwater aquifer's delaying action serves the same purpose as the power producer's surface reservoir in smoothing streamflow variations.

Water resource regulators and planners also need to understand the interdependencies among competing uses so that they can properly manage the resource.

This paper presents a methodology for quantifying the water use interdependencies and thus a mechanism for assessing the costs and benefits resulting from water use changes.

METHODOLOGY

The methodology was developed for the Canyon Ferry Reservoir and drainage basin with its ongoing irrigation and hydropower operations. However, it is quite general and thus applicable wherever agriculture and hydropower compete for water. Figure 1 is a schematic of the Canyon Ferry drainage system.

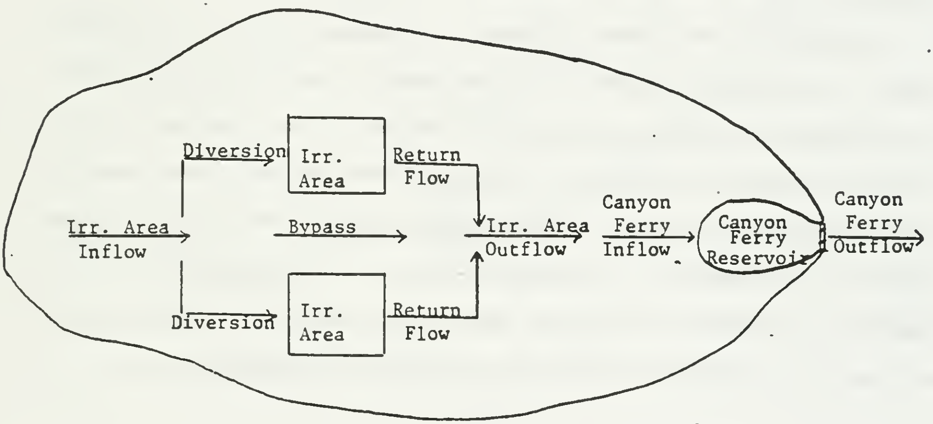

Figure 1. Schematic of the Canyon Ferry Drainage.

The irrigation operation in the basin is obviously dependent upon the diversion of water to the irrigated area. The hydropower operation is dependent upon Canyon Ferry Reservoir inflow. However, since this inflow is derived from the irrigated area return flow and bypass (streamflow not diverted), the hydropower operation is in effect also dependent upon the irrigation diversion.

A methodology was developed to simulate the basin's irrigation and hydropower operations so that the impact of changes in irrigation activity (changes in irrigation efficiency or acreage irrigated) might be assessed. Important features of the methodology are discussed in the following sections with particular attention given to the development of the methodology and to the assumptions employed in that development. Such assumptions, though limiting by nature, are absolutely necessary in a large and diverse hydrologic system such as the Canyon Ferry catchment.

Simulation of the system of Figure 1 is accomplished in the following manner. The hydrologic response of the aggregate irrigated area is determined for a specified sequence of irrigation diversions. The irrigated area outflows thus obtained are taken into the Canyon Ferry Reservoir where reservoir operation procedures and mass balance considerations determine their ultimate disposal. Key elements of the simulation, i.e., area aggregation, the irrigated area response, the reservoir mass balance requirement, and the reservoir operation procedures, are discussed under separate headings below.

AGGREGATION OF IRRIGATED AREAS

As indicated above, and as suggested by Figure 1, the irrigated areas within the Canyon Ferry drainage are considered in aggregate. Although this idealization effectively ignores the irrigation caused spatial and temporal variations in water distribution that actually exist within the basin, it does not materially affect the hydrologic behavior of the basin as a whole (the concern of this study). This fact can be seen from a consideration of Figure 2.

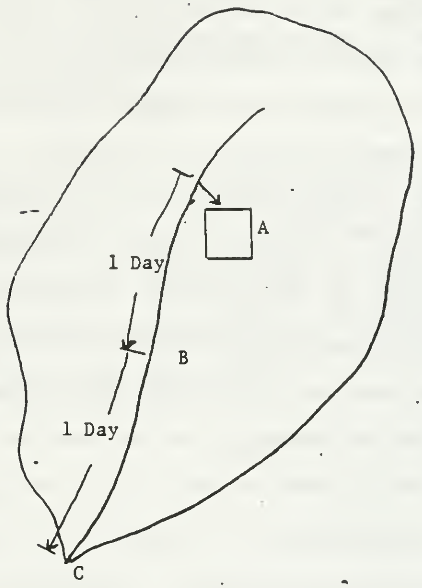

Figure 2. The effect of aggregating irrigated areas.

An irrigation diversion at A reduces the streamflow at all points below A. The subsequent return flow from that diversion increases the flow at all points below A. If the same diversion and irrigated area were at B (instead of A), the streamflow impact would be the same but it would be felt only at points below B. Thus, the streamflow within the basin (between A and B) is materially affected by the change in the point of diversion. However, the streamflow from the basin as a whole (at C) is affected only to the extent

that the impact of the diversion and return flow is felt one day later when the diversion is made at the same point in time but at A rather than B. This is due to the greater instream travel time from A (Figure 2).

Within the Canyon Ferry catchment, instream travel times from the various important irrigation sites are quite similar. It is estimated that instream travel times to Canyon Ferry from most of the important irrigation sites are on the order of 1 to 4 days (a distance of 50 miles per day is traversed with a stream velocity of 3 ft/s). Thus, placement of the aggregate irrigated area at a location about 2 days distant from Canyon Ferry would result in flow response discrepancies of from 1 to 2 days for some irrigated areas.

The effect of aggregation and the resultant streamflow response discrepancy must also be viewed in terms of the time frame selected for simulation. A response discrepancy of 1 to 2 days is very significant if the simulation interval is a day or even a week. It is much less significant if the interval is a month. In this study, a time interval of one month is used and the travel time from the aggregate irrigated area is assumed to be zero days, i.e., water is assumed to flow directly from the aggregate area into Canyon Ferry Reservoir.

The aggregation of irrigated areas and neglect of instream travel time greatly simplify the analysis with minimal loss in rigor. Furthermore, they are dictated by data inadequacies. The daily data (streamflow, etc.) required to properly assess instream travel time delays between irrigated areas are not available.

HYDROLOGIC RESPONSE OF THE IRRIGATED AREA

Simulation of the hydrologic response was accomplished by requiring that

the continuity equation and the return flow equation be satisfied for the aggregate irrigated area. The development and utilization of these equations are described in the following sections.

Continuity Equation

Mass (water) is conserved in the hydrologic system of Figure 1. The continuity equation, a mathematical statement of this fundamental physical principle, thus provides a basis for characterizing the systems hydraulic behavior. The continuity or balance equation written for the reach of stream traversing the aggregate irrigated area (Figure 3) is

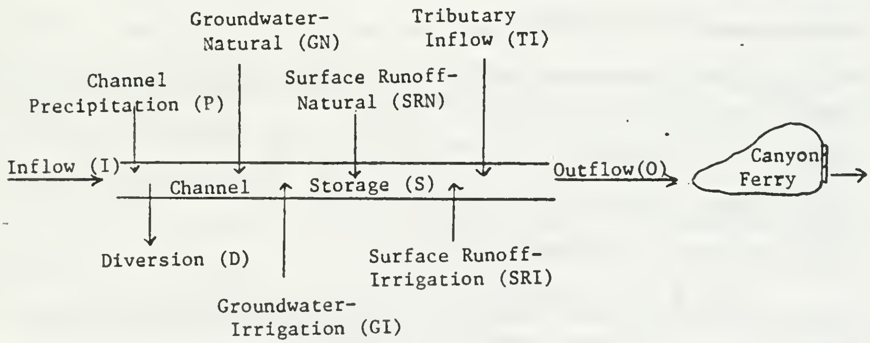

Figure 3. Stream reach through aggregate irrigated area.

$$\dot{I} + \dot{P} + T\dot{I} + S\dot{R}N + S\dot{R}I + \dot{G}N + \dot{G}I - \dot{D} - \dot{O} = \frac{ds}{dt}$$

where $\dot{I}$, $\dot{P}$, etc. are instantaneous volumetric flow rates. Note that surface runoff and groundwater flow from natural processes are identified separately from those resulting from irrigation activity. The equation states that the total instantaneous volumetric inflow rate to the reach minus the total instantaneous volumetric outflow rate from the reach must equal the instantaneous rate of change of water storage in the reach.

Because instantaneous rates are not a concern in this study (nor are such measurements generally available), the equation is approximated as

$$\bar{I} + \bar{P} + \bar{TI} + \bar{SRN} + \bar{SRI} + \bar{GN} + \bar{GI} - \bar{D} - \bar{O} = \frac{\Delta s}{\Delta t}$$

where $\bar{I}$, $\bar{P}$, etc. are time-averaged flow rates over the interval Δt. The equation may also be written

$$(\bar{I} + \bar{P} + \bar{T}I + S\bar{R}N + S\bar{R}I + \bar{G}N + \bar{G}I - \bar{D} - \bar{O})\Delta t = \Delta S = S_2 - S_1$$

where S_1 and S_2 represent respectively the water volume stored in the channel reach at the beginning and end of the time interval Δt. When the time-averaged volumetric flow rates within the parentheses are multiplied by Δt, a volumetric relationship results.

$$I + P + TI + SRN + SRI + GN + GI - D - O = S_2 - S_1$$

where I, P, etc. are volumetric accumulations during Δt. It is this volumetric form of the continuity or balance equation that is employed in this study. As previously indicated, the time interval Δt is a month. Thus I, for example, represents the volumetric inflow to the reach over a month's time.

The equation may be used to determine any one term provided all of the other terms are known. Unfortunately numerous terms in the equation are

unknown. Fortunately not all terms are of equal significance (magnitude) and consequently their neglect does not materially disturb the equality.

Because channel storage within the irrigated reach, S, is not known nor easily determined, the change in storage, S_2-S_1, on the right side of the equation is neglected. The significance of this neglect can be qualitatively assessed as follows. If the travel time through the somewhat nebulous stream reach of Figure 3 is on the order of 1.5 days, then the reach is refilled approximately 20 times each month and inflow is 20 times larger than storage. The change in channel storage, S_2-S_1, is of course considerably less than S. Thus it can be argued that the storage change, S_2-S_1, on the right side of the equation is relatively quite small compared to the inflow on the left side and can therefore be neglected without greatly disturbing the equality.

Similar relative magnitude arguments could be presented to justify the neglect of channel precipitation P, natural surface runoff SRN, and natural groundwater flow GN within the limited reach of Figure 3. Fortunately, as will be demonstrated later, it is not necessary to ignore these quantities even though individually they are unknown. The continuity equation is now

$$(I + TI + P + SRN + GN) + (SRI + GI) - D - O = 0 \qquad (1)$$

The terms are rearranged and the parentheses introduced to facilitate further discussion.

The terms within the first set of parentheses represent natural inflow to the reach while the terms in the second set represent irrigation caused inflow. Irrigation return flow (SRI + GI) is derived from and dependent upon the irrigation diversion D. The mathematical characterization of this physical dependency, an essential element of the hydrologic simulation methodology, is discussed in the following section.

Irrigation Return Flow

The application of irrigation diversion water is not 100 percent efficient. A portion of the applied water typically runs off of the surface while another portion percolates beneath the root zone to recharge the groundwater system. These waters ultimately reach the stream as the previously identified irrigation surface runoff SRI and irrigation groundwater flow GI in the continuity equation. The magnitude of the groundwater and surface water irrigation return is dependent upon the magnitude of the irrigation diversion and upon the efficiency and method of application of the diversion. Proper evaluation of the continuity equation is dependent not only upon the magnitude of these two return flows but also upon the timing of the returns. It is the latter of these dependencies, the timing of the returns, that is addressed in the following paragraphs.

The timing of surface returns from irrigation applications is easily dealt with. It is assumed that the overland flow time from the point of irrigation water application to the stream is negligible. Thus the surface return from a given diversion appears at the stream during the same month in which the diversion is made. In view of the close proximity of the irrigated areas to the streams in the Canyon Ferry drainage, this assumption is believed to be quite reasonable and thus a very minor source of simulation error.

The treatment of groundwater returns is more complex because the returns are much slower and continue over a much longer period of time. The groundwater return from a given irrigation application decreases exponentially with time and thus supplements streamflow for many months after the month of irrigation application.

Glover (2) developed a procedure for determining groundwater return that is based on a parallel drain concept. Hurley (3) used the procedure to quantify return flow to the Rio Grande River from the irrigated Mesilla Valley in New Mexico. The procedure yielded a return flow pattern that agreed quite well with the observed return flow pattern. The physical basis for Glover's procedure is presented in the following paragraphs.

When a differential form of the one-dimensional continuity equation is combined with the Dupuit-Forchheimer assumption for the control volume between the parallel drains of the isotropic, homogeneous aquifer of Figure 4, the resulting equation may be written

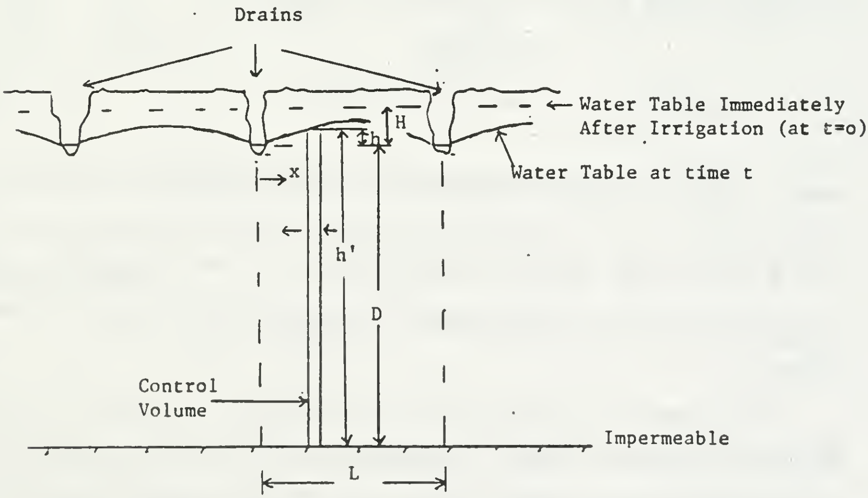

Figure 4. Parallel drains.

$$\frac{K}{S}\frac{\partial}{\partial x}\left(h'\frac{\partial h'}{\partial x}\right) = \frac{\partial h'}{\partial t}$$

or

$$\frac{K}{S}\frac{\partial}{\partial x}(D+h)\frac{\partial h}{\partial x} = \frac{\partial h}{\partial t}$$

where K is aquifer hydraulic conductivity and S is aquifer storage coefficient (specific yield). If h, the drainable depth, is small compared to D, as it is in many field situations, the nonlinear equation can be linearized by neglecting h

$$\frac{K\ D}{S}\frac{\partial^2 h}{\partial x^2} = \frac{\partial h}{\partial t} \qquad (2)$$

For the conditions

$h = 0$ when $x = 0$ for $t > 0$

$h = 0$ when $x = L$ for $t > 0$

$h = H$ for $0 < x < L$ when $t = 0$

the solution for h at any time t and at any location x is

$$h = \frac{4H}{\pi}\sum_{n=1,3,5....}^{\infty}\frac{e^{-\frac{n^2\pi^2\alpha t}{L^2}}}{n}\sin\left(\frac{n\pi}{L}x\right) \qquad (3)$$

where $\alpha = \frac{KD}{S} = \frac{T}{S}$. Aquifer transmissivity is denoted by T.

This solution yields the water table position h at any time after an irrigation application that instantaneously raises the water table a distance H (Figure 4).

Now suppose that instead of an instantaneous recharge, a continuous recharge at the rate i occurs. The recharge rate i is the rate at which water is reaching the water table. The units of i are length divided by time (inches per month for example). If τ is a time variable running from o to t, then the increment of recharge (water table rise dH) occurring at any time τ

may be written as $(i/s)d\tau$. Paralleling the development of Equation (3), the drainable depth dh at time t from this recharge increment would be

$$dh = \frac{4}{\pi}\ \frac{i}{S} \sum_{n=1,3,5...}^{\infty} \frac{e^{-\frac{n^2\pi^2\alpha(t-\tau)}{L^2}}}{n} \sin\left(\frac{n\pi}{L}x\right)d\tau$$

For a continuous recharge from o to t, the drainable depth at t is

$$h = \frac{4i}{\pi S}\int_o^t \sum_{n=1,3,5...}^{\infty} \frac{e^{-\frac{n^2\pi^2\alpha(t-\tau)}{L^2}}}{n} \sin\left(\frac{n\pi}{L}x\right)d\tau$$

For a constant recharge rate i, integration yields

$$h = \frac{4iL^2}{\pi^3 S\alpha} \sum_{n=1,3,5..}^{\infty} \frac{1}{n^3} \sin\left(\frac{n\pi}{L}x\right) - \frac{4iL^2}{\pi^3 S\alpha} \sum_{n=1,3,5...}^{\infty} \frac{e^{-\frac{n^2\pi^2\alpha t}{L^2}}}{n^3} \sin\left(\frac{n\pi}{L}x\right) \quad (4)$$

for the water table position h at any time t and at any location x.

By the Dupuit-Forchheimer assumption, the flow to a unit length of drain (from both sides) is

$$Q = 2KD \left(\frac{\partial h}{\partial x}\right)_{x=0} \quad (5)$$

The water table gradient, $\left(\frac{\partial h}{\partial x}\right)_{x=0}$, required to determine drain flow may be obtained by differentiating Equation (4) with respect to x and evaluating the derivative at x = o. Substitution of the gradient so obtained into equation (5) yields the inflow to a unit length of drain at any time t,

$$Q = iL\left[1 - \frac{8}{\pi^2} \sum_{n=1,3,5...}^{\infty} \frac{e^{-\frac{n^2\pi^2\alpha t}{L^2}}}{n^2}\right]$$

The cumulative inflow volume per unit length of drain at any time t after the continuous recharge starts is obtained by integrating Q with respect to t from o to t,

$$\int_o^t Qdt$$

Dividing the cumulative volume of drain inflow at time t by iLt, the cumulative groundwater recharge at time t, yields

$$R = \frac{\int_o^t Qdt}{iLt} = 1 + \frac{8}{\pi^4}\left(\frac{L^2}{\alpha t}\right) \sum_{n=1,3,5...}^{\infty} \frac{e^{-n^2 \pi^2 \left(\frac{\alpha t}{L^2}\right)}}{n^4} - \frac{1}{12} \left(\frac{L^2}{\alpha t}\right) \qquad (6)$$

Inspection of this equation reveals that R is a function of α, t and L. The equation has been evaluated and the results tabulated in terms of $\frac{dt}{L^2}$ (2). The tabulation provides a means for determining drain inflow (return flow) when groundwater recharge is continuous at the constant rate i. As can be seen from Equation (6), an R value (from the tabulation) represents the cumulative return flow volume at time t expressed as a percentage of the cumulative recharge at time t.

Equation (6) does not directly yield return flows for the more common situation when recharge is neither continuous nor at a constant rate. However it does provide the basis for determining such returns. The principle of superposition, which states that solutions to linear equations are additive, is employed in dealing with this situation. Consider the continuous groundwater recharge of Figure 5.

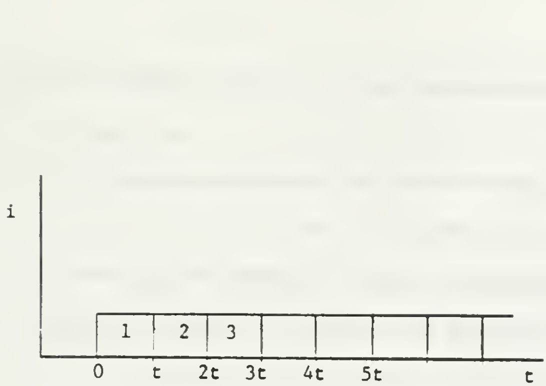

Figure 5. Continuous groundwater recharge at a constant rate i.

The recharge period may be divided into equal intervals (periods 1,2,3,------ in this example). Because Equation (2) is linear, return flows from the separate periods are additive. Stated another way, the return flow from a particular period is independent of the previous return flow history. It follows that a part of the return flow that appears during period 3 is from the recharge during period 1, part is from the recharge during period 2, and part is from the recharge during period 3. If the portion of the period i recharge that appears during period j is designated r(i,j), the cumulative return flow at the end of the third period, R_3, can be written

$$R_3 = r(1,1) + r(1,2) + r(1,3) + r(2,2) + r(2,3) + r(3,3) \quad (7)$$

Similarly, the cumulative return flow at the end of period 2 is

$$R_2 = r(1,1) + r(1,2) + r(2,2) \quad (8)$$

and at the end of period 1 is

$$R_1 = r(1,1) \quad (9)$$

The values R_1, R_2, and R_3 can be determined from Equation (6). A manipulation of these three equations yields the value r(1,3), the return flow during

period 3 from the recharge of period 1. As will be shown, this and similarly determined quantities r(1,2), r(1,4), r(1,5), etc. are essential elements in the determination of return flows from groundwater recharge that is neither continuous nor at a constant rate.

The value of r(1,3) can be obtained in the following manner. Subtraction of the cumulative return flow of Equation (8) from the cumulative return of Equation (7) yields

$$R_3-R_2 = \Delta R_{3-2} = r(1,3) + r(2,3) + r(3,3) \tag{10}$$

The quantity ΔR_{3-2} is simply the total return flow that appears during the third period. It consists of return flows from recharges during periods 1,2, and 3. Subtraction of Equation (9) from Equation (8) yields the return flow that appears during period 2.

$$R_2 - R_1 = \Delta R_{2-1} = r(1,2)+r(2,2) \tag{11}$$

It consists of return flows from recharges during periods 1 and 2. As previously pointed out, return flow response from a particular recharge event is independent of the previous return flow history. Thus the identical recharge events of Figure 5 result in identical return responses, but displaced in time. It then follows that

$$r(1,2) + r(2,2) = r(2,3) + r(3,3)$$

and that Equation (10) may be written

$$\Delta R_{3-2} = r(1,3) + r(1,2) + r(2,2) \tag{12}$$

Subtraction of Equation (11) from Equation (12) yields

$$\Delta R_{3-2} - \Delta R_{2-1} = r(1,3)$$

This is the return flow that appears during period 3 from the recharge during period 1. Similar manipulation of these and other R values (determined from Equation (6) evaluated at 4t, 5t, etc.) yields additional r(1,j) values. The return flow volumes r(1,1), r(1,2), r(1,3),----, thus obtained characterize

the return flow response from the period 1 recharge on a period by period basis.

If $r(1,j)$ values are determined for a first period unit volume recharge ($i\Delta t = 1$), then each $r(1,j)$ value can be thought of as a percentage. That is, $r(1,j)$ is the percentage of the unit recharge during period 1 that appears in period j. When tabulated, these percentages (factors) provide a means for determining the return flows when groundwater recharge is neither continuous nor at a constant rate. Consider the time distribution of recharge shown in Figure 6.

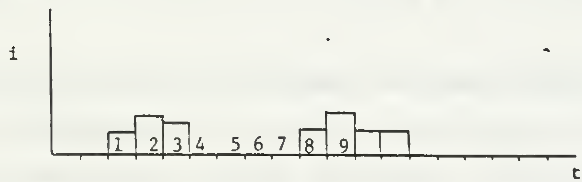

Figure 6. Noncontinuous groundwater recharge at a variable rate i.

If V_i is the recharge volume during period i, then the return flow during period j resulting from the period i recharge is $r(i,j)V_i$. The total return flow during period 5, for example, is

$$r(1,5)V_1 + r(2,5)V_2 + r(3,5)V_3 + r(4,5)V_4 + r(5,5)V_5$$

As previously described, return flow responses to identical recharge events are identical but displaced in time. Thus

$$r(2,5) = r(1,4)$$

$$r(3,5) = r(1,3)$$

$$r(4,5) = r(1,2)$$

$$r(5,5) = r(1,1)$$

and the total return during period 5 is

$$r(1,5)V_1 + r(1,4)V_2 + r(1,3)V_3 + r(1,2)V_4 + r(1,1)V_5$$

In the example of Figure 6, there was no recharge during period 4 or 5 and so $V_4 = V_5 = 0$ and the total return during period 5 is

$$r(1,5)V_1 + r(1,4)V_2 + r(1,3)V_3$$

From the table of previously determined $r(1,j)$ values and specified period recharge volumes, V_i, the total return flow during the 5th period can be determined. The return flow during any other period can be determined in a like manner.

Computed $r(1,j)$ values, the basis for the return flow determination, become smaller as j becomes larger, but they do not mathematically go to zero. Thus, return flows from a particular recharge event become progressively smaller with time but continue indefinitely. From a practical standpoint however, when $r(1,j)$ values and associated return flows become very small, and substantially all (say 99.9%) of the event recharge has returned, it is reasonable to assume that subsequent $r(1,j)$ values are zero and that return flow from that event ceases.

The return flow determination procedure just described can be extended to situations where the recharge rate is continuously varying if the continuously varying rate can be reasonably approximated by a stepwise rate variation as shown in Figure 7 below.

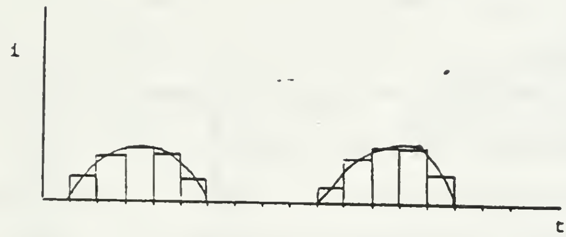

Figure 7. Stepwise approximation of continuously varying recharge events.

The stepwise approximation is of course like the recharge variation of Figure 6 and can be dealt with in the same way.

Assuming that the recharge of Figure 7 is the result of an irrigation application that is similarly distributed in time, it follows that the previously described computational procedures provide a link between irrigation diversions (applications) and groundwater return flows. The procedures are appropriate for an irrigated area bordered by parallel drains that are spaced a distance L apart as in Figure 4. An equivalent problem is one in which a valley of width L is drained by a stream midway between the valley borders (Figure 8).

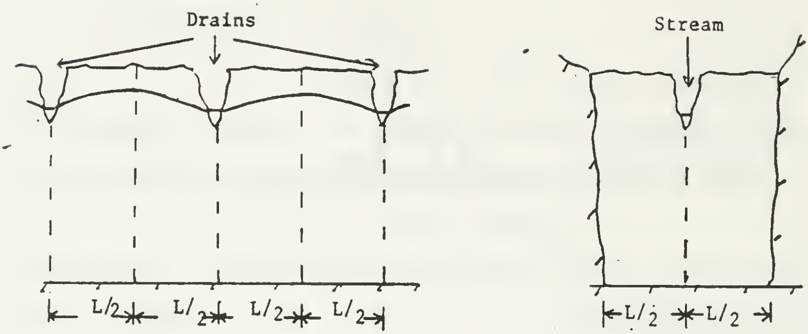

Figure 8. Parallel drains and stream valley.

The problems are equivalent because in each case the flow is zero through a vertical plane located a distance L/2 from the drain.

As will be discussed in more detail later, the two idealized flow situations of Figure 8, along with Equation 6 and the relationships derived therefrom, provide the basis for computing ground water return flows in the Canyon Ferry drainage.

Combined Use of the Continuity and Return Flow Relationships

The continuity equation, as previously developed for the stream reach traversing the aggregate irrigated area, is

$$(I + TI + P + SRN + GN) + (SRI + GI) - D - O = 0 \qquad (1)$$

where the terms are as defined in Figure 3. The equation may be solved for any one unknown provided all other quantities are known. Certain of the terms in the equation are linked through the previously discussed surface and ground water return flow relationships. Thus surface return from irrigation, SRI, and ground water return from irrigation, GI, can be determined if irrigation diversions, D, are known. It follows that if total reach inflow (I + TI + P + SRN + GN) and diversions are known, then reach outflow, O, can be determined.

With reference to Figure 3, it can be seen that total reach inflow (I + TI + P + SRN + GN) consists of reach inflow I, tributary inflow TI, precipitation that falls directly on the channel P, natural surface runoff SRN, and natural ground water recharge (or discharge) GN. To directly determine total inflow would require many measurements. Reach inflow, for instance, would require streamflow measurements on all streams that enter the various irrigated areas. Natural ground water recharge (or discharge) would require sophisticated and difficult measurements at many locations. Similar problems would be encountered in the direct determination of the other components of the total inflow. Thus direct determination of separate inflow components is not feasible. However, indirect determination of the combined or total inflow (the concern of this study) is feasible via the continuity equation. As previously stated, the continuity equation may be solved for any term provided all other terms are known. Thus if reach outflows O and diversions D (and therefore irrigation returns SRI and GI) are known, total inflow can be determined. In the Canyon Ferry system, historical diversions and irrigated reach outflows are known and consequently total inflow can be determined. The inflow thus determined is the "natural" inflow to the irrigated area. Once established, this "historical" record of inflow can be used to assess the impacts of changes in irrigation activity. This is accomplished by solving

the continuity equation again, but this time for outflow O. In this application of the continuity equation, total inflows (computed total inflows) and diversions (real or assumed) are known. A comparison of results for various assumed irrigation diversions and efficiencies reveals the impacts of changes in irrigation activity.

Characterization of the irrigated area's hydrologic behavior, as described in this section, has necessarily utilized many assumptions. Where appropriate the assumptions have been discussed with regard to their reasonableneas and their ramifications. The reasonableness of some of the assumptions, however, can only be judged by comparing the assumed condition to real physical condition. For example, the assumption of an isotropic, homogeneous aquifer may be reasonable for some real aquifers and unreasonable for others. Until the physical character of the real aquifer is examined, the reasonableness of the assumption cannot be judged. Further discussion of such assumptions must therefore await the more detailed description of the Canyon Ferry system presented in a later section.

RESERVOIR MASS BALANCE

The irrigated area outflow of the previous section flows into the Canyon Ferry Reservoir. As with the irrigated area stream reach, mass (water) is

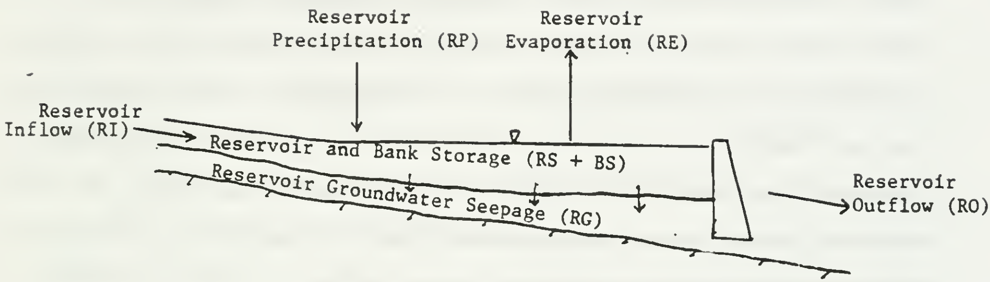

Figure 9. Canyon Ferry Reservoir.

conserved in the reservoir (Figure 9) and the continuity equation may be written

$$RI + RP - RE - RG - RO = RS_2 + BS_2 - RS_1 - BS_1$$

where the terms are as identified in the figure. The terms RI, RP, etc. on the left side of the equation are volumetric accumulations during the month. The terms on the right side, RS_2, etc. are storage volumes at the beginning and end of the month. The subscript 1 identifies the beginning-of-the-month storage while the subscript 2 identifies the end-of-month storage. System storage consists of two components: reservoir storage RS and bank storage BS.

The equation can be solved for any one term provided all other terms are known. Thus a rigorous solution demands that monthly values be known for all of the independent variables for the period of interest. Because such a data base does not exist for the Canyon Ferry system, some rigor must be

sacrificed. The following paragraphs identify the terms in the continuity equation that were neglected in this study. The significance of that neglect is also addressed.

A complete lack of information about bank storage made it necessary to neglect bank storage change (BS_2 - BS_1). Bank storage changes with reservoir level. A rise in reservoir level produces an hydraulic gradient that causes water to flow into the adjacent soil where it is stored until a falling reservoir level reverses the gradient and causes water to flow from the soil into the reservoir. The amount of water stored in the soil depends upon the reservoir level, the soil's storage coefficient (specific yield), and the extent of the soil as determined by the bed rock configuration. Although the volume stored may be quite large, the monthly change in volume stored (BS_2 - BS_1) is much less. The monthly volume change is dependent upon the monthly reservoir level change which at Canyon Ferry is usually on the order of a few feet or less. Annual fluctuations of the reservoir level at Canyon Ferry are typically on the order of 15 feet or so. Thus the neglect of bank storage changes in the continuity equation is not expected to materially affect the equality.

Groundwater seepage was also neglected in this study. The seepage term, RG, represents groundwater flow from or to the reservoir site. It is separate from the groundwater flow associated with the temporary on-site bank storage previously discussed.

The net groundwater flow is almost certainly to the reservoir since foundation grouting at the dam severely limits groundwater flow from the site. The primary avenue of groundwater inflow is believed to be the alluvial aquifer beneath and adjacent to the Missouri River. For an aquifer width of 2 miles, an aquifer transmissivity of 120,000 gal/day/ft, and a gradient of 10

ft/mile (assumed, but reasonable values), the groundwater inflow would be about 220 A-ft/mo. This inflow is negligible compared to the reservoir surface inflow RI which averages 171,000 A-ft even during the low flow month of August. Thus the neglect of reservoir seepage, RG, will have little effect on the equality expressed by the continuity relationship.

The continuity equation was further simplified by the neglect of precipitation on and evaporation from the Canyon Ferry Reservoir surface (RP and RE respectively). This neglect disturbs the continuity equality somewhat more than the previous ones.

Because RP and RE have opposite signs (in the continuity equation), the neglect of one compensates in part for the neglect of the other. The significance of neglecting RP and RE varies from month to month, but is generally greatest in August when evaporation is high and precipitation is low. An evaporation loss of 5 inches and a precipitation gain of 1 inch (typical August figures) result in a net loss of approximately 12,000 A-ft from the 35,000 acre reservoir surface. This is 7 percent of the average reservoir inflow during August (171,000 A-ft). The neglect of evaporation and precipitation during other months is relatively less significant of course, because the evaporation-precipitation differential is generally less and because the reservoir inflow is considerably greater.

On the basis of the idealizations discussed above, the continuity equation for the reservoir takes on the much simpler form

$$RI - RO = RS_2 - RS_1$$

This equation provides the basis for operating the reservoir. Recall that the known (computed) outflow from the aggregate irrigated area becomes inflow to Canyon Ferry (RI). Thus for a specified beginning-of-the-month storage RS_1, the reservoir outflow RO can be varied in such a way that a desired

end-of-the-month storage RS_2 may be achieved. The monthly outflow and end-of-the-month storage are generally selected to meet some reservoir operational objective or objectives.

RESERVOIR OPERATION PROCEDURES

Canyon Ferry is a multipurpose facility. In addition to its power production function, it provides flood control, irrigation water storage, and recreation. It also serves an important function in the maintenance of flows for downstream power producers and recreationalists. All of these functions (and possibly others) should be considered in the operation of the reservoir. That is not to say that they should all be given equal consideration. Some functions are more important than others. Some functions are satisfied by default. Reservoir recreational objectives, for example, are reasonably met within the reservoir surface level range dictated by flood control and power generation considerations.

The reservoir operation procedures (rules) used in the simulations of this study are presented and discussed below. Operational decisions, based on these rules, are made on a monthly basis.

1. Reservoir capacity (2,050,900 A-ft at water surface elevation 3,800 ft) cannot be exceeded. Water is released (regardless of downstream channel capacity) to meet this requirement.

2. Downstream flow is limited to channel capacity (15,000 cfs) whenever reservoir storage is available to so limit.

3. Reservoir storage in excess of 1,946,624 A-ft (water surface elevation 3,797 ft) is reserved for flood control. This storage is used only when failure to do so would cause the downstream channel capacity (15,000 cfs) to be exceeded.

4. Reservoir releases for Helena Valley irrigation and pump turbine discharge are maintained at historical levels regardless of the impact on reservoir storage.

5. Reservoir releases to satisfy the minimum downstream flow requirement (2,500 cfs) are made regardless of the impact on reservoir storage.

6. When not limited by the constraints specified above (1-5), reservoir releases are dictated by specified month-end storage goals. The amount of water released is such that the month-end storage goal will be met (or at least approximated).

7 Subject to the constraints above (1-6), and the performance characteristics of the turbines, turbine discharge is regulated in a manner designed to maximize energy production.

Operation rules 1-3 require little discussion. Observance of rule 1 assures that the dam will not be overtopped. Rule 2 requires that any available storage must be used to reduce downstream flows to or toward 15,000 cfs. Rule 3 requires that the top 3 ft of reservoir storage be reserved exclusively for flood control. This storage is used only when failure to do so would cause flooding (discharges greater than 15,000 cfs) downstream.

Rule 4 recognizes the priority of the Helena Valley and pump turbine reservoir releases. Actually these releases have historically been quite limited and consequently have little effect on reservoir operation.

A minimum downstream flow is provided by Rule 5. Thus downstream users (power producers, irrigators, recreationalists, etc.) are assured a water supply during periods of water shortage. Although somewhat arbitrary, the minimum flow requirement used in this study (2,500 cfs) is believed to be quite reasonable.

Rule 6 addresses the seasonal differences in reservoir operation procedures that are mandated by seasonal changes in reservoir inflow and user needs. The rule is applied within the constraints of the previous 5 rules. During some months, reservoir operation is totally determined by rules 1-5. For example, downstream flow is limited to channel capacity whenever reservoir storage is available according to rule 2. Furthermore, if the only available

storage is flood control storage, rule 3 requires that the downstream channel be used to capacity. Thus releases are totally constrained and rule 6 is not considered. However, during most months, operation is not completely constrained by rules 1-5, and it is during these months that rule 6 becomes operational.

Rule 6 requires that the month-end reservoir storage be brought to (or near) a specified storage goal provided rules 1-5 are not violated in so doing. This is accomplished by increasing or decreasing reservoir releases.

The month-end storage goals are based on historically observed month-end storage volumes at Canyon Ferry. The January, February, etc. storage goals are essentially the averages of the January, February, etc. month-end storage volumes. Storage goals range from 1,500,000 A-ft (water surface elevation 3,783 ft) in March to 1,940,000 A-ft (water surface elevation 3,797 ft) in June.

Rule 7 requires that the available releases, as determined above (1-6), be used to maximize energy production. In other words, water must not be spilled at the expense of energy production.

It should be noted that these seven reservoir operation rules only approximate actual reservoir operation procedures. They do not, for example, consider the recreational use of the reservoir. However, as was previously pointed out, this use is reasonably satisfied within the constraints imposed by rules 1-7.

The seven reservoir operation rules outlined and discussed above adequately account for the most important factors upon which Canyon Ferry operations depend. They do so in several ways. Most reservoir use objectives such as flood control, energy production, etc. are of course directly addressed by the rules. Other objectives, such as the maintenance of reservoir

recreational opportunities, though not directly addressed by the rules, are reasonably well met within the constraints imposed by the rules. Additionally, the reservoir storage goals of rule 6 play a not so obvious role in meeting operational objectives. These goals are based on historical storage records. The historical storage volumes are the results of decisions which were presumably aimed at meeting the combined reservoir use objectives. The goals therefore implicitly reflect all of the combined operational objectives. It follows that all operational objectives are at least indirectly addressed when these goals are targeted in rule 6.

Although quite reasonable overall, the reservoir operation procedures do have certain deficiencies which should be noted. In actual reservoir operations, snowmelt runoff forecasts are considered in the determination of spring reservoir releases. These forecasts are not utilized in the simulations of this study. However, the snowmelt management objective is indirectly considered in that the historically based month-end storage goals reflect that objective.

A second operational deficiency results from the fact that the rules are applied on a monthly basis. Actual reservoir operation decisions may be made on a daily (or even hourly) basis. Although otherwise generally adequate, the monthly operations schedule is inadequate for flood management. A flood of several days duration obviously cannot be properly managed with a monthly operations schedule. The inability to manage floods is of limited significance however, given the infrequency of occurrence of floods that require reservoir management.

One other operational deficiency results from the rigidity of the rules. Actual reservoir operation procedure are more flexible and sometimes change over time. A perusal of the Canyon Ferry operation records, for instance,

suggests that energy production has become an increasingly more important operations objective over the years. It would also appear that the reservoir's flood control function has changed over the life of the facility. Such changes, particularly progressive changes, in operational objectives are very difficult to simulate with rigid reservoir operations rules. Inflexibility in reservoir operation procedures is not totally disadvantageous however. The effects of changes in irrigation activity, for example, can be better assessed when viewed in the framework of an unchanging reservoir operations procedure.

The operational deficiencies described in the previous paragraphs, though disadvantageous, are not seriously so. Thus the overall operation of the reservoir can be satisfactorily simulated with the seven specified reservoir operation rules.

METHODOLOGY SUMMARY

Simulation of the system of Figure 1 is accomplished in the following manner. The hydrologic response of the aggregate irrigated area is determined for a specified sequence of irrigation diversions. The continuity equation and the ground water return flow equation are the key elements in this response determination. The response thus determined, the irrigated area outflow, becomes the inflow to Canyon Ferry Reservoir. That inflow is routed through the reservoir in a manner that satisfies the continuity equation and also satisfies (to the extent possible) the reservoir use objectives.

Application of the methodology to the Canyon Ferry system is described in the following section.

CANYON FERRY SYSTEM

Canyon Ferry Reservoir is located on the Missouri River in west central Montana (Figure 10). The reservoir is a multipurpose facility. Among its most important purposes are storage, regulation of downstream flows, flood control, energy production, and recreation. The reservoir has a surface area of 35,000 acres and a total storage volume of 2,050,000 Acre-ft.

The Canyon Ferry catchment includes most of southwest Montana. It is bounded by the continental divide to the west and south and by the Gallatin and Bridger ranges to the east. The major streams that drain the area are the Gallatin, Madison, and Jefferson Rivers, plus the two major Jefferson River tributaries, the Big Hole and the Beaverhead Rivers. The Missouri River is formed by the confluence of the Gallatin, Madison, and Jefferson Rivers. Southwestern Montana is mountainous and the streams are fed primarily by snowmelt with peak discharges generally occurring in May or June.

The climate in southwestern Montana is simiarid with annual precipitation accumulations on the order of 15 inches or less in the tillable valleys. Where available, irrigation waters are used to augment precipitation in the production of hay and other crops.

The features of the Canyon Ferry system that are relevant to the methodology of this study are discussed under separate headings below.

AGRICULTURAL ACTIVITIES

Although irrigation is practiced at many locations, probably 90 percent of it is concentrated at the locations identified by the cross-hatched areas of Figure 10. Irrigation activities are in general quite similar at the various locations. Irrigation waters are diverted from streams and applied to lands that are in close proximity to the streams (bottom lands, benches, and alluvial fans). Though occupying different stream basins, the irrigated lands

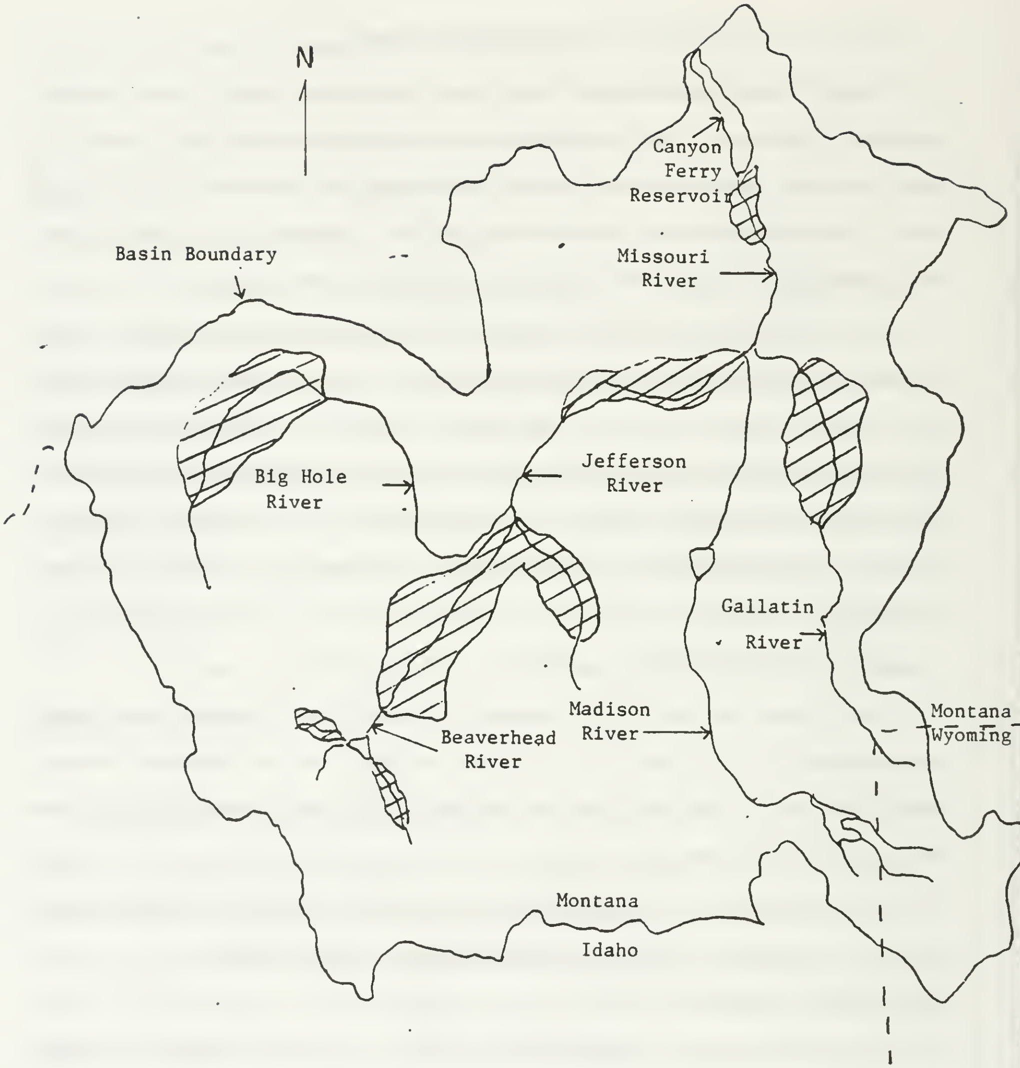

Figure 10. Canyon Ferry study area.

are of similar geologic origin and depositional character, and thus hydrologically similar. Irrigation methods are also quite similar throughout the drainage. Flood irrigation using contour ditches to deliver the diverted surface water to the fields is most common. Sprinkler irrigation, though less common, has become increasingly more important in recent years.

As discussed at length in the methodology section, these irrigated areas (hydrologically similar and similarly managed) are treated in aggregate in this study.

Irrigation Diversions and Crop Consumptive Use

Irrigation waters are diverted from streams at many locations within the basin. Unfortunately, the diversion flow rates are regularly measured at only a very few locations. Diversion totals (and consumptive use totals) for the basin must therefore be estimated. The Water Conservation and Salvage Report for Montana, a Soil Conservation Service publication (1), provides such estimates. The estimates are based on available diversion measurements, data on crop types, acreages, and consumptive needs, and on firsthand knowledge of the areas and the irrigation operations.

The report estimates annual irrigation diversions, crop consumption needs, etc. on county by county basis. The monthly basin-wide figures required for this study were obtained from the annual county figures in the following manner. Annual basin-wide totals are determined from the county figures and from the hydrologic maps in the publication titled "An Atlas of Water Resources in Montana by Hydrologic Basins" (4). The maps show the basin boundaries, the county boundaries, and the irrigated areas within the counties (and basin). They thus provide a basis for determining what fraction of each

county's irrigation activity takes place within the basin and correspondingly what fraction of that county's diversions, etc. are within the basin. The annual basin totals (the summed county fractions) are then allocated on a monthly basis over the irrigation season. The allocation is based on historical diversion records from the region. The presumption is that these records are indicative of diversion timing throughout the basin.

The annual basin wide totals for irrigation diversion and for crop consumptive use were found to be 3,503,400 Acre-ft and 651,300 Acre-ft respectively. Diversion timing (and consumptive use) was assumed to be as follows: 25% of the annual total diverted in each of the three months of June, July, and August; 10% of the annual total in each of the months of May and September; and 2.5% of the annual total in each of the months of April and October. The amount and timing of the diversions (and consumptive use) were assumed to be the same from year to year. Additional details about the determination of the basin-wide irrigation figures can be found in Appendix A.

Irrigation Efficiency

Irrigation efficiency is herein defined as the ratio of the crop consumptive use to the irrigation diversion. Based on the annual totals of the previous paragraph, it follows that the irrigation efficiency of the aggregate area is 19% (651,300 ÷ 3,503,400). The irrigation efficiency is assumed to be the same (19%) for each month of the irrigation season.

A very large portion of the irrigation diversion (81%) is not beneficially used in crop production. The disposal of this water is discussed in the following sections.

Nonbeneficial Consumptive Use

The Water Conservation and Salvage Report for Montana (1) states that in addition to beneficial crop consumptive use within the basin, there is also nonbeneficial consumptive use. This nonbeneficial use (by phreatophyes that border ditches, etc.) is estimated to be 25% of the beneficial use. This water, along with the beneficially consumed water, is of course lost to the Canyon Ferry hydrologic system.

Surface Return Flow

A portion of the unconsumed irrigation diversion returns to the stream via the surface. During the months of April, May, and June, it is assumed that 25% of each month's diversion returns this way. During July, August, September, and October, 15% of each month's diversion is assumed to return in this way. Although somewhat arbitrary, these percentages are believed to be reasonable, and to reflect to some degree the more relaxed management that prevails during the water rich months of April, May and June.

It is assumed that these surface flows return to the stream during the same month in which they are diverted. This is quite reasonable in view of the close proximity of the irrigated areas to the streams.

Groundwater Recharge

The remainder of the irrigation diversion (the irrigation diversion minus the consumed water and the surface return) recharges the ground water aquifer. It does so via ditch seepage losses and deep percolation through the root zone. It is assumed that the groundwater system is recharged during the same month in which the water is diverted and applied to the fields. This

assumption does not imply that the downward moving water necessarily traverses the partially saturated zone in a very short period of time, but rather it implies that the soil moisture content in the partially saturated zone is constant (near field capacity) and consequently recharge (excess over crop consumptive need) to that zone from above must equal discharge from that zone to the ground water system below.

GROUNDWATER

Ground water return flows move from the recharge areas (irrigated areas) through the aquifer to the surface drainage system. The time delay associated with that movement is dependent upon the aquifer properties and upon the location and configuration of the drains.

Aquifer Properties

In the early 1950's, the United States Geological Survey (USGS) carried out a comprehensive study of the groundwater resources of the Gallatin Valley (5). As part of the study, aquifer tests were conducted to determine the properties of the alluvial deposits underlying the irrigated areas of that valley. These test results provided the basis for quantifying the aggregate aquifer properties. Specifically, it was assumed that the aggregate aquifer properties were the same as those of the Gallatin Valley aquifer. Although somewhat of a necessity (no other substantive aquifer tests have ever been conducted in the areas of concern), the assumption is never-the-less believed to be quite reasonable. The irrigated lands and underlying aquifers are hydrologically similar. Though in different basins, they typically occupy

similar settings close to streams. The aquifers are also of similar geologic origin and depositional character.

In the course of the U.S. Geological Survey study, aquifer tests were conducted at numerous locations across the irrigated areas of the Gallatin Valley. Test results indicate fairly large variations in aquifer properties with little or no spatial pattern in those property variations. This is not surprising in view of the depositional character of the aquifer. Sediments have been carried from the nearby mountains by numerous streams. Over geologic time, these streams have changed continuously in terms of discharge, sediment load, channel configuration, and channel location. The result is an alluvial aquifer that exhibits a tremendous variation in sediment size, ranging from large boulders to silt and clay size. Though generally well mixed, there are deposits of well sorted materials such as sand or gravel stringers and clay lenses. These well sorted deposits are typically limited in extent and more-or-less randomly distributed.

The alluvial deposits described above are of Quaternary age. They are underlain by much less permeable deposits of Tertiary age. The alluvial deposits, the concern of this study, are variable in thickness. The USGS study found alluvium thickness to vary from only a few feet to as much as 400 feet with thicknesses on the order of 50 to 120 feet being most common.

The alluvial Quaternary aquifer described in the previous paragraphs is obviously not homogeneous - at least not on a local scale. This is borne out by the variability in the USGS aquifer property values. However, the absence of any pattern in the spatial variation in aquifer properties suggests that the aquifer might be considered homogeneous on a large scale. In other words, the randomly heterogeneous aquifer with its varied properties may be reasonably approximated by a homogeneous aquifer with properties that are the

average of the heterogeneous aquifer properties. This sort of idealization is appropriate when investigating the overall behavior of the irrigated area ground water system. It would not be appropriate for investigating localized ground water flows within the irrigated area. Because the concern of this study is overall aquifer behavior, the aquifer is considered to be homogeneous with averaged aquifer properties. The assumption of homogeniety employed in the development of the return flow equation (methodology section) is thus justified.

A condition of aquifer isotropy was also assumed in the development of the return flow relationship. Unfortunately, no aquifer tests were conducted to assess the isotropy of the Gallatin Valley aquifer. The mode of sediment deposition in the alluvial aquifer however, does suggest certain things about the isotropy of the aquifer. When equidimensional sediments are deposited by flowing water, they have no preferred depositional orientation. However, when nonequidimensional particles such as those most commonly found in intermountain alluvial basins are deposited, they tend to be positioned with the largest dimensions parallel to the depositional surface (Figure 11).

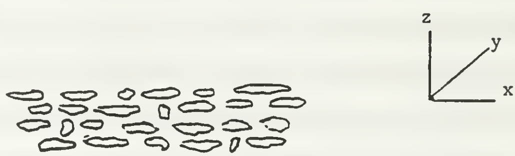

Figure 11. Depositional orientation of alluvial sediments.

This preferred orientation causes the deposits to be anisotropic with the hydraulic conductivity in the vertical z direction typically significantly less than the equal horizontal x and y direction conductivities. The anisotropy must be taken into account when the ground water flow velocity has a significant vertical component. However, when the flow is strictly horizontal, the anisotropy is not a factor. The ground water flow in the irrigated areas is predominantly horizontal, and consequently the assumption of aquifer isotropy in the return flow equation development is not unreasonable. The horizontal nature of the irrigated area groundwater flows is discussed in more detail in the next section on drain configuration.

USGS tests conducted within the irrigated areas of the Gallatin Valley yielded values for aquifer transmissivity T (aquifer conductivity times aquifer saturated thickness) ranging from 4,500 to 670,000 gal/day/ft. Transmissivities were generally much less variable than these extremes might suggest, however. The average transmissivity on the alluvial plain (24 test sites) was 212,000 gal/day/ft. The average transmissivity on the alluvial fan deposits (6 test sites) was 41,000 gal/day/ft. The average aquifer transmissivity, based on an approximate area weighting, was assumed to be 120,000 gal/day/ft. The individual well transmissivities upon which the average transmissivity is based are presented in tabular form in Appendix B.

The USGS study unfortunately provides only limited information about the storage coefficient S of the Gallatin Valley aquifer. The aquifer tests conducted in the study were either single well tests, which yield no information about the storage coefficient, or short duration multiple well tests. Although the storage coefficient can be determined from a multiple well test, the coefficient value tends to be deceptively small when the test

is of short duration. This is primarily because the analysis upon which the coefficient determination is based assumes an instantaneous and total release of available water from the pore space as the water table falls during testing. In actuality, the available water is released at an exponentially decreasing rate over time. As a consequence of this gradual release, the computed value of the storage coefficient tends to increase and approach a constant value as the duration of the aquifer test increases. Because this study considers ground water level fluctuations on a monthly basis, it is concerned with the longer term (1 month) release of water from the dewatered portion of the aquifer and the storage coefficient that characterizes that release.

The USGS estimated that the average storage coefficient for the Gallatin Valley alluvium would be about 0.05 after 12 hours of pump testing and much larger after several weeks of pumping. On the basis of this information, and on the basis published storage coefficient estimates for similar alluvial deposits, a coefficient of 0.20 was assumed appropriate for the aquifer.

These values of the storage coefficient S and the transmissivity T are used in the determination of the groundwater return flows from the Canyon Ferry aggregate irrigated area. Recall from the methodology section that the return flow determination was based on the return flow factors, r(1,j), and that these factors are functions of $\frac{\alpha t}{L^2}$, where $\alpha = T/S$, t is time, and L is drain spacing (discussed in next section). A tabulation of the Canyon Ferry system return flow factors is presented in Appendix C.

Drain Configuration

The groundwater return flow determination procedures developed in the methodology section were for an idealized surface drain configuration. The procedures are appropriate for a system of parallel drains spaced a distance L apart or for a single drain centered in a valley of width L (Figure 8). These idealizations may be only approximately satisfied in real groundwater drainage systems.

Maps prepared by the Montana State Engineer's Office (6,7) show that irrigated lands in southwestern Montana are traversed by numerous effluent streams and drains. Although the configurations of these drains (natural and man-made) are varied, they can generally be roughly approximated by the idealized configurations described above. The configuration of a single drain centered in a valley of width L is approximated in some of the narrower irrigated valleys in the Canyon Ferry drainage (Figure 12).

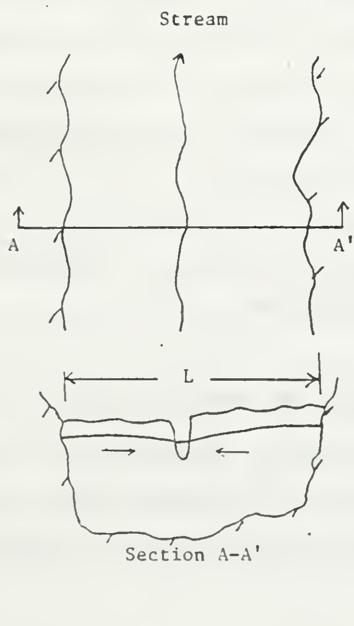

Figure 12. Valley-centered drain (stream).

In the broader intermountain alluvial basins such as the Gallatin Valley, the surface drainage network in the irrigated areas tends to be dendritic. These dendritic networks closely resemble a system of parallel lateral drains connected by mains in a herringbone pattern (Figure 13).

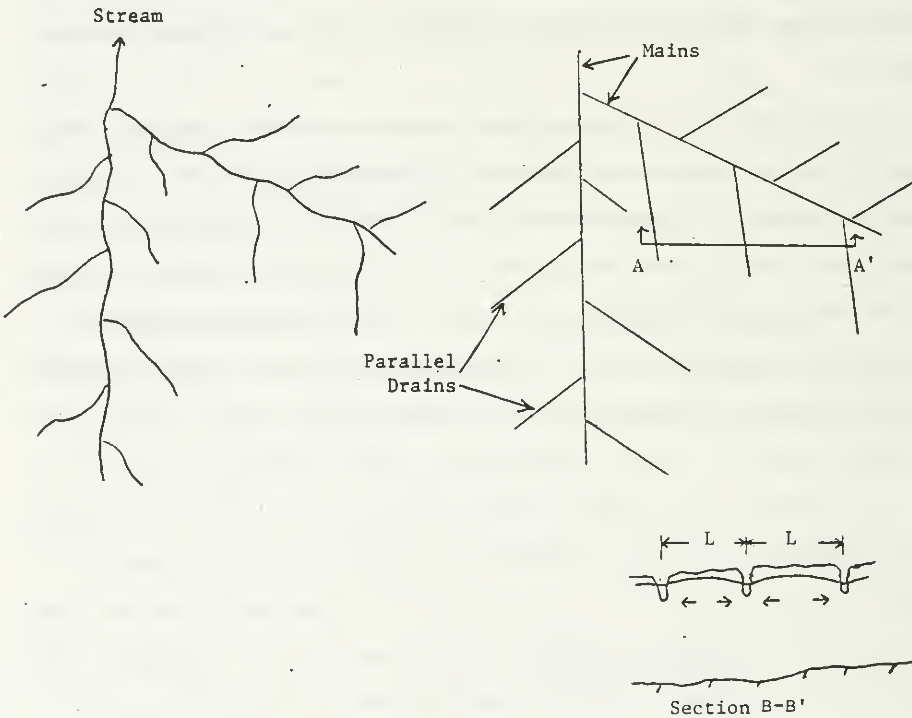

Figure 13. Dendritic drain pattern.

Thus the areal configurations of the existing drains in the Canyon Ferry drainage are reasonably approximated by combinations of the idealized drain systems of the methodology section. The distance between "parallel" drains, as determined from the State Engineer's Office publications (6,7) is

estimated to average about 1.5 to 2 miles. A drain spacing L of 2 miles was assumed in this study.

In addition to the idealized areal drain configuration, certain other idealizations were employed in the development of the groundwater return flow computation procedures in the methodology section. Specifically,it was assumed that the drainable depth h was much less than the saturated thickness D (Figure 4), that the groundwater flow was horizontal and one-dimensional (in the x direction of Figure 4), and that the Dupuit-Forchheimer idealization was appropriate for characterizing the groundwater flow velocity. The appropriateness of these three assumptions is dependent upon the saturated thickness of the aquifer, the uniformity of that thickness, and the vertical position of the drain in the saturated thickness. As with the previously discussed areal drain configuration idealization, these idealizations may be only approximated in the real groundwater system. With reference to the typical aquifer sections of Figures 12 and 13 (sections A-A' and B-B' respectively), it can be seen that the drainable depth is much less than the aquifer's saturated thickness. Recall that the aquifer thickness, although somewhat variable, was generally in excess of 50 feet. The depth of the drains is generally on the order of 10 feet or less, resulting in a drainable depth of less than 10 feet and a saturated thickness in excess of 40 feet. With reference again to the cross sections of Figures 12 and 13, it can also be seen that, though not strictly horizontal, the groundwater flow is predominately horizontal and one-dimensional in a direction toward the drain. The appropriateness of the Dupuit-Forchheimer assumption is also apparent from the cross sections in that the slope of the water table is small and the aquifer's saturated thickness is large as required for application of the assumption.

Thus the idealizations employed in the development of the groundwater return flow computation procedures in the methodology section are reasonably satisfied in the real groundwater system. It follows that those computational procedures can reasonably be used to determine groundwater return flows from the aggregate irrigated area in the Canyon Ferry drainage.

SURFACE WATER

A greatly simplified surface water system results from the previously discussed aggregation of irrigated areas (Figure 1). As suggested by the figure, streamflows of concern are those flowing into the irrigated area, those flowing out of the irrigated area (and into the reservoir), and those flowing out of the reservoir. Also of concern of course,is the temporary storage afforded the streamflow by the Canyon Ferry Reservoir.

Streamflow

Recall that this study considers total inflow to and total outflow from the aggregate irrigated area (Figure 1). It does not consider individual stream inflows or outflows. Recall also that the total inflow, the "natural" inflow, is computed from the known total outflow by means of the continuity and return flow relationships. The "natural" inflows thus computed then become the surface water data base for subsequent analyses as the inflows are subjected to various assumed irrigation use demands and the basin response is simulated (irrigated area outflows, etc. are simulated). Thus the only streamflow records required for the desired hydrologic simulations are those for total outflow from the aggregate irrigated area. Total outflow is

essentially the same as the inflow to Canyon Ferry Reservoir (see discussion under "Aggregation of Irrigated Areas" section), and records of Canyon Ferry inflow, as determined by the Bureau of Reclamation, are available in the Bureau's Canyon Ferry Reservoir operation records (Appendix D). Reservoir inflow records from 1955 (the initial filling of the reservoir) through 1984 were utilized in this study.

Canyon Ferry Reservoir

Outflows from the aggregate irrigated area enter Canyon Ferry Reservoir, are temporarily stored in the reservoir, and are eventually released from the reservoir. Operation of the reservoir (release scheduling, etc.) depends on many factors. The numerous use objectives of the multipurpose facility must of course be considered. Physical system constraints, such as reservoir capacity and turbine capacity, must also be considered along with operational constraints such as minimum release requirements. These and other factors that relate to the Canyon Ferry Reservoir operations are discussed in the following paragraphs.

Various in-house documents from the Bureau of Reclamation describe the Canyon Ferry facility, its operational objectives, and its historical operations. Information from these documents provided the framework upon which the simulation of reservoir operations was based. Of particular importance was the Canyon Ferry Reservoir operations record (Appendix D). This document lists reservoir inflows, outflows, storage volumes, etc. on a monthly basis over the life of the reservoir.

Water may be released from the Canyon Ferry Reservoir via the river and spillway outlets, through the power turbines, through the pump turbine, or it may be pumped to the Helena Valley. In the simulations of this study, releases through the river and spillway outlets and through the power turbines are allowed to vary. They are adjusted (via reservoir operations) in response to changes in reservoir inflow. Pumpage to Helena Valley and pump turbine discharge, however, are not allowed to vary. These releases are maintained at the historical levels (timing and amount) indicated in the Canyon Ferry Reservoir operations record.

As discussed in detail in the methodology section (under the "Reservoir Operation Procedures" heading), monthly reservoir releases are determined in part by month-end storage goals. Within the limits imposed by other constraints (minimum and maximum release requirements, etc.), releases are increased or decreased so that the month-end storage objectives can be attained, or at least approached. The month-end goals, which are intended to reflect historical reservoir operations objectives, are obtained essentially by averaging the month-end storage volumes recorded in the Canyon Ferry Reservoir operations record. The month-end storage goals are listed in Appendix E.

In addition to the direct use of the reservoir operations records described above, the records were also used as a basis for assessing the reasonableness of the simulated results. This was accomplished by comparing the various simulated results (monthly reservoir releases, storages, etc.) to their historical counterparts.

Bureau of Reclamation documents relating to turbine operating characteristics, and reservoir storage allocations provide additional information that is utilized in the simulation of reservoir operations.

Simulated power turbine performance is constrained by the turbine operating characteristics as defined by the Canyon Ferry power plant's characteristic curves (Appendix F). Simulated reservoir operations require that storage be reserved for flood control as specified in the Bureau's Canyon Ferry Reservoir allocations (Appendix F). Total reservoir storage, an obvious consideration in the simulation of reservoir operations, is also identified in this latter document.

A Bureau document titled "General Operating Principles at Canyon Ferry" (Appendix G) was extensively used in the formulation of rules for the simulation of reservoir operations. The operating principles identify various operational objectives, priorities, and constraints. The simulation rules, described in detail in the methodology section, adhere to these principles to the extent possible. Deviations from these principles are discussed in the methodology section.

Reservoir releases to the Missouri River are limited to channel capacity whenever reservoir storage space is available to so limit. The channel capacity is 15,000 cfs according to the Bureau's document on reservoir operating principles. In addition, a minimum reservoir release of 2,500 cfs is maintained at all times to satisfy downstream users (power producers, recreationalists, irrigators, etc.). Though somewhat arbitrary, this minimum flow requirement was suggested as a reasonable limit by Mr. Gordon Aycock of the Bureau of Reclamation.

SUMMARY - CANYON FERRY SYSTEM

As is apparent from the discussions of this section, it has been necessary to use numerous simplifying assumptions and idealizations in

characterizing the Canyon Ferry system. This is not surprising in view of the size and diversity of the system, and also the general scarcity of data characterizing the system. The simplifications, while sacrificing something in detail and rigor, are essential in that they make possible a reasonable simulation of the total basin's hydrologic behavior.

SIMULATIONS AND RESULTS

Recall that the primary objective of this study is to assess the hydrologic impacts that result from changes in irrigation activity in the Canyon Ferry drainage. Toward this end, numerous simulations of the basin's hydrologic behavior were made. The first simulation yielded a record of monthly irrigated area inflow. Subsequent simulations utilized this record in assessing the impacts of changes in irrigation activity. The various simulations are discussed on the following pages.

SIMULATION OF IRRIGATED AREA INFLOW

As described in detail in the methodology section, irrigated area inflows are determined by solving the continuity equation and the groundwater return flow equation for the aggregate irrigated area. The "natural" inflows thus obtained then become the surface water data base for subsequent analyses in which these inflows are subjected to various assumed irrigation use demands.

Solution of the continuity and return flow equations for irrigated area inflow requires that irrigated area outflows, irrigation diversions, and irrigation efficiencies be specified along with drainage system parameters (aquifer transmissivity, aquifer storage coefficient, and drain spacing). The variables to be specified are briefly discussed in the following paragraphs, and, with the exception of irrigated area outflow, are tabulated in Table 1. A tabulation of irrigated area outflows (Canyon Ferry inflows) may be found in Appendix D. For a more detailed discussion of the variables and procedures, refer to the previous sections on the Canyon Ferry system and on methodology.

Irrigated area outflows are assumed to be equal to Canyon Ferry inflows. Thus "historical" records of monthly irrigated area outflow may be determined

from reservoir inflows as recorded in the Canyon Ferry operations record (Appendix D).

A monthly consumptive use schedule (Table 1) was estimated from "The Water Conservation and Salvage Report for Montana" (1).

TABLE 1

Simulation Input Data

Crop Consumptive Use Schedule

Month	Consumptive Use (Acre-ft)
Oct	16,282.0
Nov	0.0
Dec	0.0
Jan	0.0
Feb	0.0
Mar	0.0
Apr	16,282.0
May	65,130.0
June	162,825.0
July	162,825.0
Aug	162,825.0
Sept	65,130.0

Irrigation Efficiency = 19%

Aquifer Transmissivity = 120,000 gal/day/ft

Aquifer Storage Coefficient = 0.20

Drain Spacing = 2 miles

This report also yielded an irrigation efficiency (consumptive use/irrigation diversion) estimate of 19 percent (See also Appendix A). Both the consumptive use schedule and the irrigation efficiency were assumed to be the same from year to year throughout the simulation period. These assumptions are only approximately true, of course. They were made out of necessity, since there are no reliable records that tabulate year to year changes in irrigation activity. Irrigation diversions were computed from the consumptive use figures and the known irrigation efficiency.

The return flow aquifer's transmissivity T and storage coefficient S were estimated to be 120,000 gal/day/ft and 0.20 respectively. Spacing between "parallel" drains L, was estimated to be 2 miles. Groundwater return flow factors, r(l,j), are a function of these variables (T, S, and L) along with time t. Return flow factors were determined for monthly time intervals and are presented in Appendix C. Recall that r(l,j) is the percentage of a unit groundwater recharge during month l that returns to the surface water system (drains) in month j. The factors thus provide a way to determine the groundwater return flow during any month from a known groundwater recharge during a specified month.

Groundwater recharge during a particular month is dependent upon the irrigation diversion during that month. A portion of the diversion is consumed, a portion returns via the surface to the stream, and the remainder recharges the groundwater system.

The "Water Conservation and Salvage Report for Montana"(1) estimates that in addition to the crop consumptive use, there is an additional consumptive use (phreatophytes, etc.) that is equal to 25 percent of the crop consumptive use. Monthly consumptive use was therefore assumed to be 125 percent of the consumptive use values in Table 1.

Surface return flows from irrigation applications typically vary through the irrigation season. In this study it was assumed that 25 percent of the monthly diversion returns to the stream via surface runoff in the water-rich months of April, May, and June, while only 15 percent returns by this route in the water-short months of July, August, September and October. These surface flows return during the same month that they are diverted. Irrigation waters that are neither consumed nor return via the surface constitute groundwater recharge.

In summary then, from the consumptive use figures of Table 1, and the current irrigation efficiency of 19 percent, monthly irrigation diversions can be computed. Monthly surface returns are taken as a percentage (specified above) of these diversions. Monthly groundwater recharge is found by subtracting the monthly surface return and monthly consumptive use from the monthly irrigation diversion. Monthly groundwater return flow is in turn determined from the monthly groundwater recharge via the return flow factors. And finally, irrigated area inflow is determined from the continuity equation,

$$(I + TI + P + SRN + GN) + (SRI + GI) - D - O = 0 \qquad (1)$$

As previously discussed, the various aggregate area inflows (left parentheses) need not, and in general cannot be separately identified. Thus the continuity equation can be written as

$$\text{Inflow} + (SRI + GI) - D - O = 0$$

where inflow is total irrigated area inflow. The equation may be solved for monthly inflow since monthly values of surface runoff from irrigation, groundwater return from irrigation, diversion, and outflow (SRI, GI, D, and O respectively) are known.

Monthly values of irrigated area inflow were determined in this manner for the period 1955 - 1984. These "natural" inflows are tabulated in Appendix

H, and a typical interval from that tabulation is shown graphically as a hydrograph in Figure 14. The irrigated area outflow hydrograph (Canyon Ferry inflow hydrograph) from which the "natural" inflow hydrograph was simulated is also shown.

The validity of the computational procedures was tested by reversing the simulation process. The previously determined inflows (Figure 14) were subjected to the same irrigation demands and irrigated area outflows were simulated. The resulting outflow hydrograph was exactly the same as the historical outflow hydrograph (Canyon Ferry inflow hydrograph). Figure 15 shows a portion of the simulated outflow hydrograph. It, along with the inflow hydrograph, is identical to the hydrographs of Figure 14 (vertical scales are different), thus demonstrating the validity of the computational procedures.

Figure 15 provides additional insight to the computational procedure for determining irrigated area outflow. The high peaked hydrograph (black line) represents the "natural" inflow to the irrigated area. The lowest hydrograph (red line) represents the bypassed flow (the "natural" inflow that is not diverted). The blue lines above that represent groundwater return flows from individual months. The uppermost blue line represents the irrigated area outflow. The outflow is obtained by summing the bypassed flow and the groundwater return flows (see Figure 16 for clarification). The outflow (dashed line) in September is obtained by summing the September bypass and the return flows from groundwater recharges during September, August, and previous months. The outflow during October is obtained by summing the October bypass and the return flows from the groundwater recharges during October, September, August, and previous months.

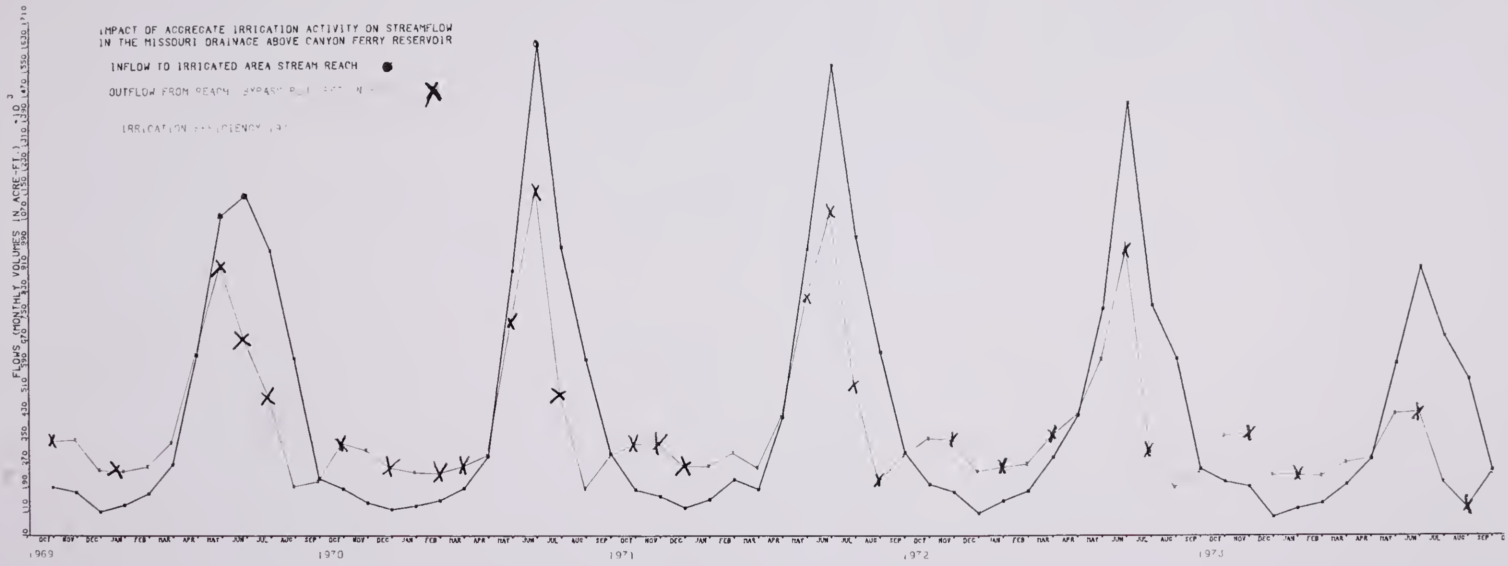

Figure 14. Irrigated area inflow ("natural" inflow) as determined from known irrigated area outflow.

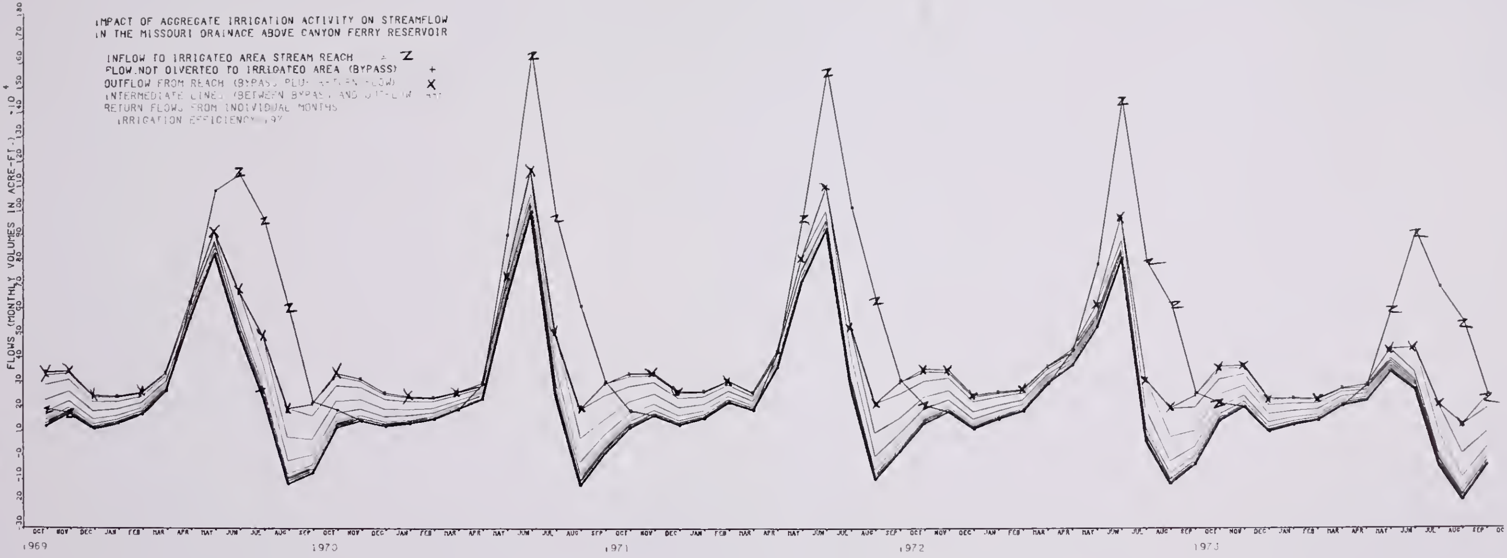

Figure 15. Irrigated area outflow as determined from "natural" inflow. Also shown are the groundwater return flows from individual months.

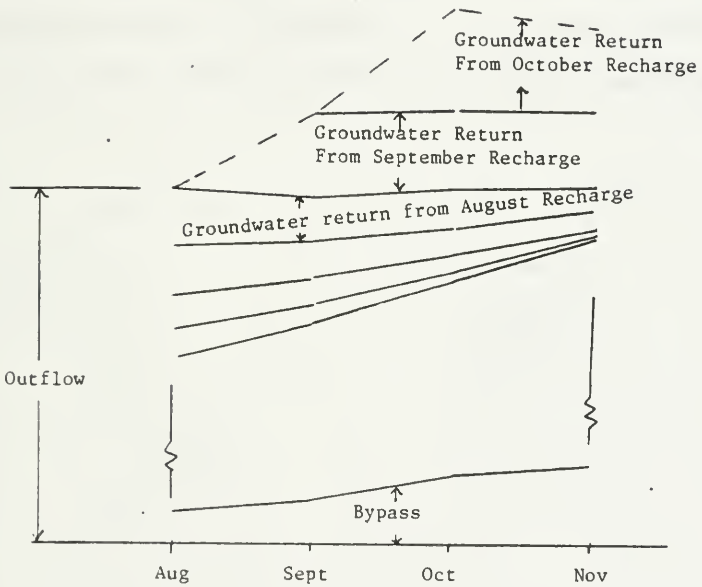

Figure 16. Irrigated area outflow.

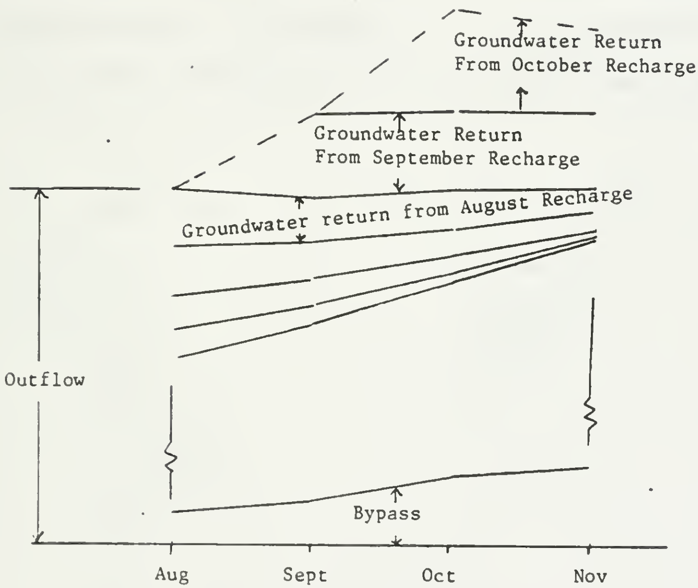

Figure 16. Irrigated area outflow.

The contribution from any month's recharge diminishes exponentially with time as indicated by the gradual convergence of the return flow lines (Figure 15).

Although the aggregate irrigated area inflows and outflows of Figure 16 are always positive, the bypass is sometimes negative. The negative bypass is a computational peculiarity that results from the aggregation of the irrigated areas. Consider Figure 17(a) in which two irrigated areas, A_1 and A_2 are considered separately. The symbols I, O, D, B, and R represent respectively inflow, outflow, diversion, bypass and return flow. Repeated application of

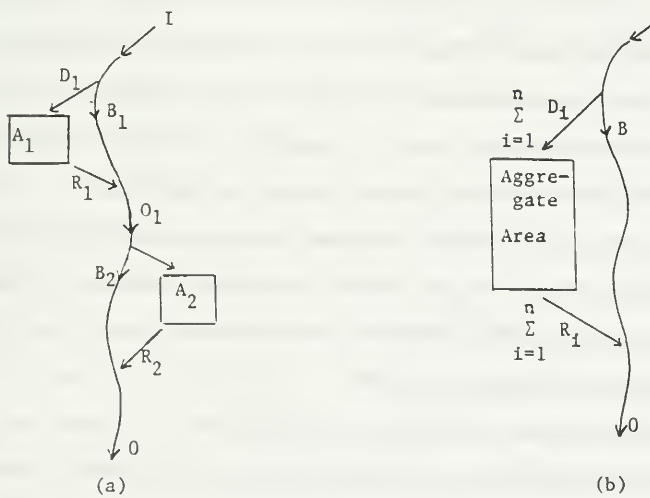

Figure 17. (a) Nonaggregated irrigated areas and (b) aggregated irrigated areas.

the continuity equation in the downstream direction yields

$$I = D_1 + B_1$$

$$O_1 = B_1 + R_1$$

$$O_1 = D_2 + B_2$$

$$O = B_2 + R_2$$

It is noted that the bypassed flows for the separate areas (B_1 and B_2) are not negative. It is not possible to divert more water from a point of diversion than flows to that point of diversion. Combining the separate continuity expressions yields

$$O = I - D_1 + R_1 - D_2 + R_2$$

or in general for n separate irrigated areas,

$$O = I - \sum_{i=1}^{n} D_i + \sum_{i=1}^{n} R_i$$

It is noted here that the total diversions can, and often do, exceed the inflow ($\sum_{i=1}^{n} D_i > I$). This typically occurs in the late summer months, and it is possible because the irrigated area inflow is augmented within the irrigated area by return flows from previous months irrigation applications. For example, irrigated area A_2 of Figure 17(a) can divert return flows from earlier irrigation applications to A_1 as well as the current month's bypass of A_1. The result is a total monthly irrigated area diversion (to A_1 and A_2) that exceeds the monthly irrigated area inflow.

Now consider Figure 17(b), a schematic representation in which the n irrigated areas have been aggregated. If the schematic's undiverted flow is defined as the bypass B (analogous to the separate irrigated area bypasses of Figure 17(a)), then repeated application of the continuity equation in the downstream direction yields

$$I = \sum_{i=1}^{n} D_i + B$$

$$O = B + \sum_{i=1}^{n} R_i$$

Combining the separate continuity expressions,

$$O = I - \sum_{i=1}^{n} D_i + \sum_{i=1}^{n} R_i$$

The equation for the outflow from the aggregate area is identical to the equation for the outflow from the unaggregated areas. Since this study is concerned with the impact of the total irrigation activity, and not with impacts within the aggregate area, the aggregation is quite acceptable. However, as was pointed in the previous paragraph, diversions may exceed inflow ($\sum_{i=1}^{n} D_i > I$), and when they do, the so-called aggregate irrigated area bypass of Figure 17(b) will be negative. The negative bypass is thus a peculiarity that results from the aggregation of irrigated areas. It does not, however, in any way invalidate the analysis.

With reference to Figure 15, it can be seen that the outflow hydrograph is less variable than the inflow hydrograph. Irrigation season outflows have generally been reduced by irrigation diversions while off-season outflows have been increased by irrigation return flows. Although variable from year to year, the hydrograph "smoothing" afforded by the diversions and delayed return is always quite significant. Early summer peaks are typically reduced by 25 percent or so. Late summer flows may be reduced by 70 percent or more. Winter flows may be increased by more than 100 percent.

The hydrograph smoothing that results from irrigation activities is of major importance. Among other things, it greatly reduces the possibility of flooding during the snow melt runoff season. It also benefits power producers in that streamflows are maintained at artificially high levels during the winter, thus permitting increased power production during this period of high demand. If the hydrograph smoothing agent, irrigation activity, is changed, the extent of the smoothing, and the benefits that derive therefrom will, of

course, be changed. The following sections investigate the effects of such changes.

SIMULATIONS OF IRRIGATION ACTIVITY CHANGES

The irrigated area inflows obtained in the previous section were subjected to specified irrigation demands and the irrigated area outflows were simulated. The outflows thus obtained were then input to the Canyon Ferry Reservoir where the previously discussed reservoir operation rules determined their ultimate disposal. Two general types of irrigation activity change were simulated: changes in irrigation efficiency, and changes in irrigated acreage.

Simulations of Changes in Irrigation Efficiency

Irrigation efficiencies, which have been increasing with expansions in sprinkler use, reductions in conveyance loss, and better management, are projected to increase even more in the future (1). The future increases will probably be gradual and perhaps sporadic as economic conditions vary. They will almost certainly occur, however, as irrigators seek to improve their profits.

More efficient irrigation operations require smaller diversions and produce less return flow, and thereby increase irrigated area outflow variability. Spring and early summer outflows are higher because of the reduced diversions and winter outflows are lower because of the reduced groundwater return flows. The increased variability in outflow (Canyon Ferry

inflow) impacts reservoir operations as they relate to power production, flood control, etc.

The effects of irrigation efficiency improvements were investigated by simulating the Canyon Ferry system's hydrologic behavior under three levels of assumed irrigation efficiency. All other system variables such as irrigated area inflow, crop consumptive needs, etc. were held constant, so that the separate effects of the efficiency changes might be assessed. Efficiencies of 19 (the estimated current efficiency (1)), 40, and 60 percent were considered in the three simulations. It is recognized, of course, that the higher efficiencies, particularly the 60 percent efficiency, might never be attained. Simulations of these efficiency conditions are never-the-less useful in that they clearly identify the character and relative significance of the efficiency changes.

Simulation results were summarized in a series of graphs. Portions of these graphs (covering the period from 1969 through 1973) are shown in the following figures. Each of the graphs includes four records: the historical record (Bureau of Reclamation) and one record for each of the three simulated irrigation efficiencies.

The first graph, Figure 18, shows how Canyon Ferry inflow is affected by changes in irrigation efficiency. Because the simulated inflow hydrograph for the 19 percent irrigation efficiency (estimated current efficiency) is coincident with the historical inflow hydrograph, only 3 hydrographs are evident in the figure. The reservoir inflow hydrograph peaks are increased as the irrigation efficiency is increased and correspondingly less water is diverted. As will be shown in subsequent figures, the increased spring reservoir inflows necessitate more frequent use of the reservoir's flood control storage as well as reservoir releases that more frequently exceed the

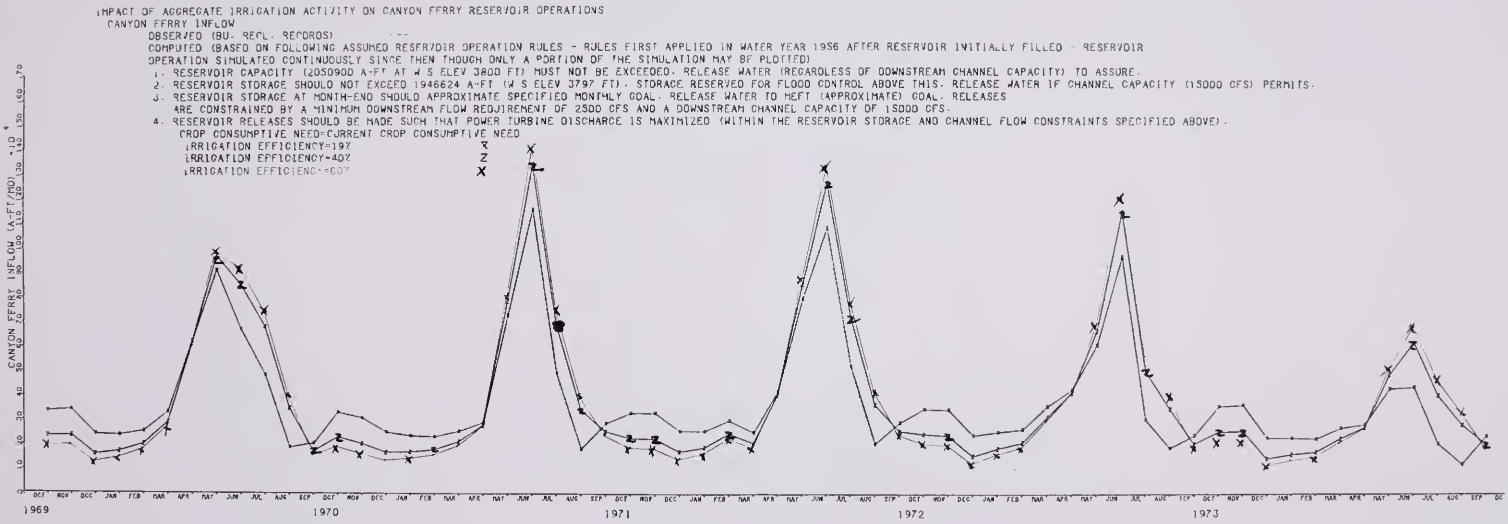

Figure 18. The effects of changes in irrigation efficiency on Canyon Ferry inflow.

below-dam channel capacity. Figure 18 also shows that winter reservoir inflows decrease with increases in irrigation efficiency and the resultant reductions in groundwater return flow. Although variable, reductions in Canyon Ferry winter inflow range up to 45 percent and more when irrigation efficiency is increased from 19 to 60 percent. As will be shown in subsequent figures, these reduced inflows limit energy production during the winter months.

The next four figures (19, 20, 21, and 22) illustrate how Canyon Ferry operations are impacted by the changes in irrigation efficiency and the resultant changes in reservoir in flow. In these figures, the simulated records for the estimated current irrigation efficiency of 19 percent (solid black lines) are not coincident with the historical records (dashed black lines). These differences result from the fact that the operations rules employed in the simulations deviate somewhat from those that were historically employed in the operation of the reservoir. It would be very difficult, probably impossible, to specify a set of reservoir operations rules that would, when applied in a simulation, yield reservoir storages, etc. that were identical to historical records of storage, etc. The historical records reflect a rather complex and evolving set of flexible reservoir operations procedures that were applied in the daily operation of the reservoir. The simulation rules, on the other hand, are necessarily simpler, less flexible, and they are applied on a monthly basis. These simpler rules never-the-less produce a reasonable simulation of historical reservoir operations (compare solid and dashed black lines). The reader is referred to the section titled "Reservoir Operation Procedures" for a detailed discussion of the operations rules and the rationale behind them.

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Figure 19 shows how the month-end reservoir storage varies with changes in irrigation efficiency. The reservoir operations rules, which are stated on the figure, were the same in each of the three efficiency simulations. Thus the plots in Figure 19 (and in Figures 20, 21 and 22) illustrate impacts that are solely attributable to changes in irrigation efficiency. It can be seen from the figure that month-end storage generally becomes more variable as irrigation efficiency increases and that flood control storage (above upper horizontal line) must be more frequently and more extensively used. During the period from 1968 through 1984 , it was necessary to use this storage during 6, 11, and 13 years for respective irrigation efficiency simulations of 19, 40, and 60 percent. Figure 19 also shows that reservoir storage falls below that level at which head limits power production (middle horizontal line) more frequently as irrigation efficiency increases.

Figure 20 illustrates how the discharge below the dam (total reservoir release to the Missouri River) varies with changes in irrigation efficiency. It can be seen that the channel capacity is exceeded more often and more extensively as irrigation efficiency increases. The reservoir operations rules permit the channel capacity to be exceeded only when flood control storage (Figure 19) is exhausted. During the period from 1968 through 1984, it was necessary to exceed channel capacity during 0, 8, and 9 years for respective irrigation efficiency simulations of 19, 40 and 60 percent.

Figure 21 shows how power turbine discharge is affected by changes in irrigation efficiency. The most notable effects are the reductions in winter turbine discharge that accompany increases in irrigation efficiency. Although variable, the winter discharge may be reduced as much as 50 percent when the irrigation efficiency is increased from 19 to 60 percent. This is primarily

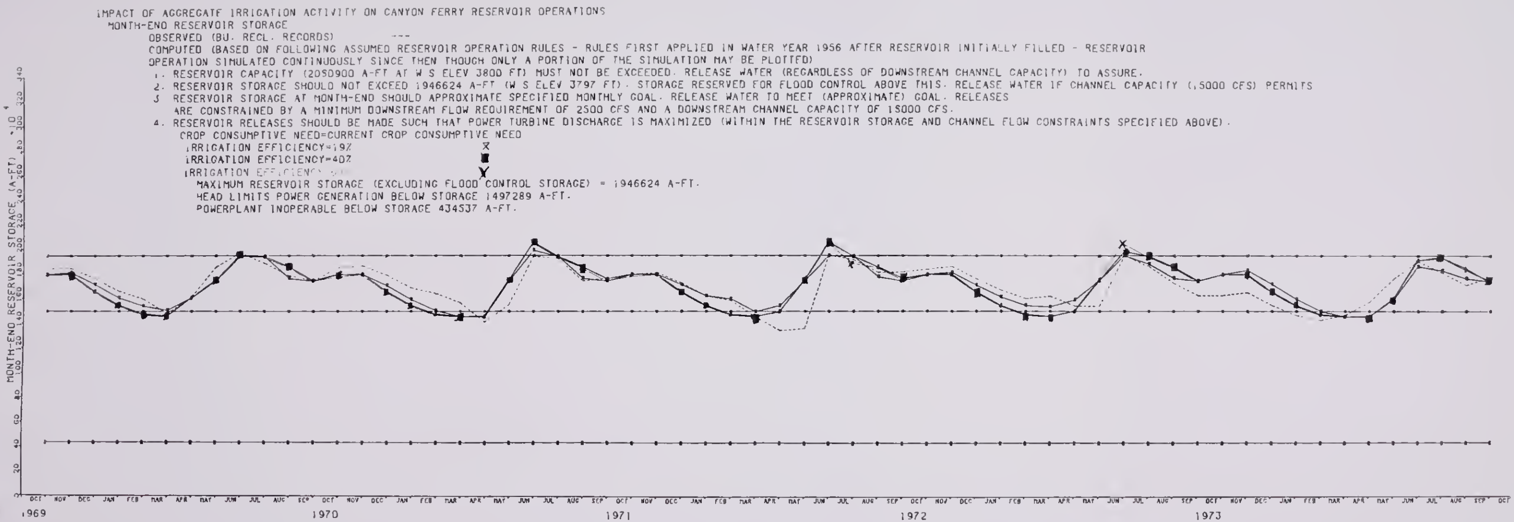

Figure 19. The effects of changes in irrigation efficiency on Canyon Ferry month-end storage.

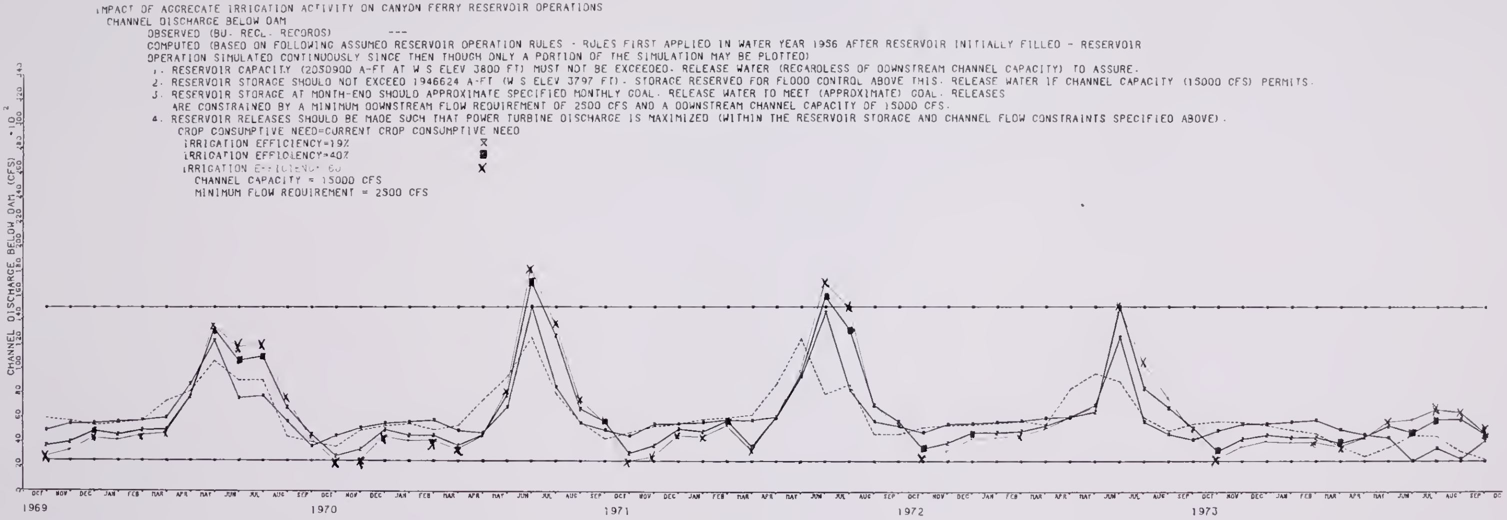

Figure 20. The effects of changes in irrigation efficiency on Canyon Ferry releases to the Missouri River.

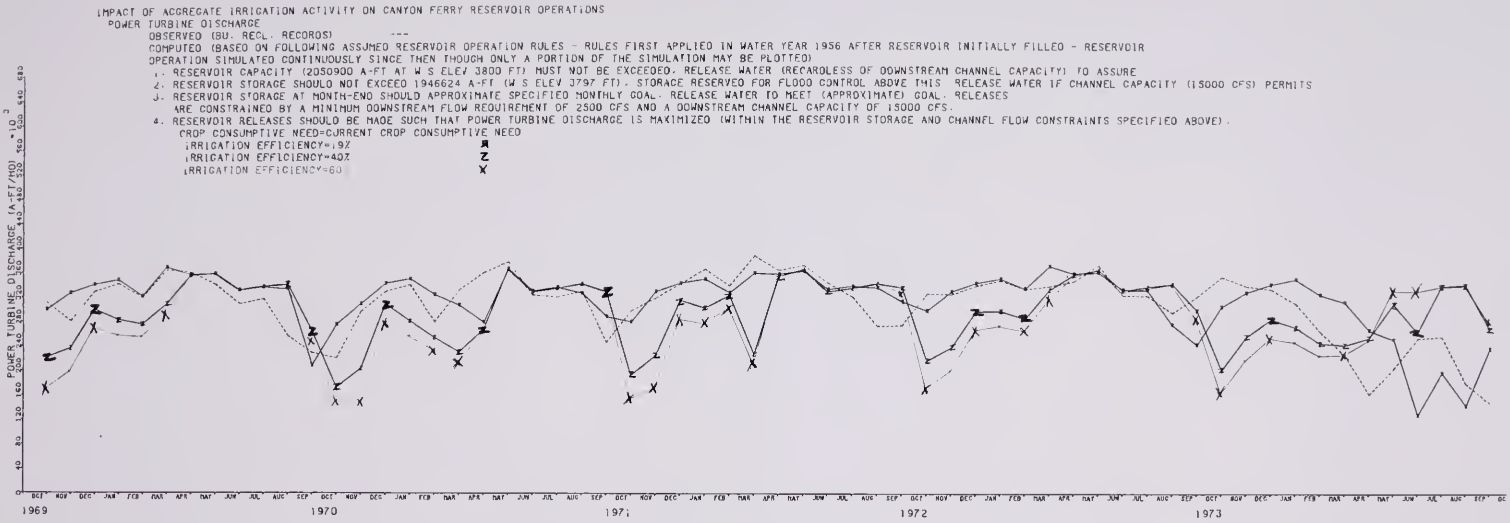

Figure 21. The effects of changes in irrigation efficiency on Canyon Ferry power turbine discharge.

because of the reduced winter groundwater returns that are associated with the higher irrigation efficiency (see low winter reservoir inflows at higher efficiencies in Figure 18). The increased efficiency has little effect on turbine releases during the summer months in most years. That is because the reservoir inflows in the spring are usually high enough (even when reduced by the increased diversions required for low irrigation efficiency operations) to satisfy turbine discharge needs during these months. However, during very dry years such as 1973 (see low spring reservoir inflows in Figure 18), the summer turbine discharge may be significantly affected by changes in irrigation efficiency. The increased spring inflows that result from the smaller diversions required by the more efficient operation permit larger summer turbine releases (Figure 21). Such increased releases, however, draw down the reservoir and this action generally necessitates a reduction in turbine releases during the following winter.

Energy production is dependent upon turbine operating characteristics, turbine discharge, and turbine head (and thus reservoir storage). These quantities are related through the power plant's operating characteristic curves (Appendix F). As discussed in the previous paragraphs, reservoir storage and turbine discharge are affected by changes in irrigation efficiency. It follows then that energy production, which is dependent upon reservoir storage and turbine discharge, is also affected by changes in irrigation efficiency. Figure 22 illustrates how energy production is affected by such changes. The curves of this Figure are quite similar to those of Figure 21 since energy production is strongly dependent upon turbine discharge. It can be seen from Figure 22 that winter energy production generally decreases as irrigation efficiency increases. This is primarily a consequence of the reduced turbine discharge that results from the diminished winter groundwater

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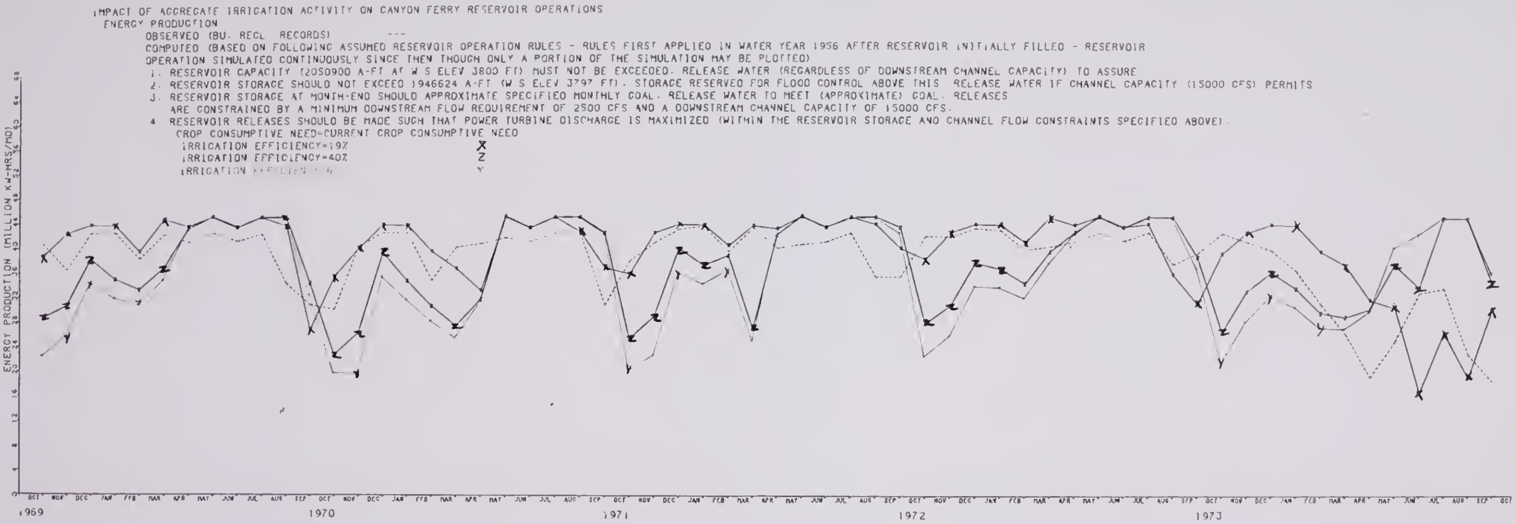

Figure 22. The effects of changes in irrigation efficiency on Canyon Ferry energy production.

return flows associated with the increased efficiencies. It can also be seen that during a very dry year such as 1973, an increased level of summer energy production is possible at the higher irrigation efficiency levels. This is primarily due to the increased turbine discharge during this period, and as with the turbine discharge, it generally comes at the expense of a reduction in energy production during the following winter.

Table 2 below further illustrates how energy production is affected by changes in irrigation efficiency. The table lists the average monthly energy production in millions of Kw-Hrs for the period from 1968 through 1984.

TABLE 2

Average Energy Production (Kw-Hr x 10^6) from 1968-84

Month	Observed Bureau of Reclamation	Simulated for 19% Irrigation Efficiency	Simulated For 40% Irrigation Efficiency	Simulated For 60% Irrigation Efficiency
Oct	35.4	34.9	25.9	22.7
Nov	37.1	39.3	28.0	23.7
Dec	41.7	43.9	38.1	32.5
Jan	42.2	43.4	34.6	31.7
Feb	36.8	39.1	32.1	29.1
Mar	39.0	40.6	32.1	30.0
Apr	37.3	39.4	38.1	37.8
May	38.8	41.6	42.5	42.8
June	39.0	39.3	41.1	42.2
July	39.8	40.9	44.8	44.8
Aug	35.3	36.8	44.5	44.9
Sept	31.0	34.0	38.1	38.1
Annual	453.3	473.2	440.1	420.3

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Mar	39.0	40.6	32.1	30.0
Apr	37.3	39.4	38.1	37.8
May	38.8	41.6	42.5	42.8
June	39.0	39.3	41.1	42.2
July	39.8	40.9	44.8	44.8
Aug	35.3	36.8	44.5	44.9
Sept	31.0	34.0	38.1	38.1
Annual	453.3	473.2	440.1	420.3

It can be seen that the average annual energy production (bottom of table) is reduced as irrigation efficiency is increased. More importantly, the time distribution of monthly energy production is significantly changed by the irrigation efficiency changes. In general, winter energy production is reduced and summer energy production is increased as irrigation efficiency is increased.

As evidenced by Figures 18 through 22 and by Table 2, it must be concluded that increases in irrigation efficiency can have a rather significant impact on Canyon Ferry inflow and thereby Canyon Ferry operations.

Simulations of Changes in Irrigated Acreage

There is a demand for more extensive use of the surface water resource in the Canyon Ferry drainage basin. Applications for such use (primarily for irrigation) are periodically received and reviewed by the state's Water Rights Bureau.

An increase in irrigated acreage requires an increase in the irrigation diversion (assuming no change in irrigation efficiency). A portion of the diversion increase is consumed within the newly irrigated area and a portion of it returns to the stream system via surface runoff and groundwater flow. The consumed portion is of course lost to the system and total irrigated area outflow is correspondingly reduced. The surface runoff component of the diversion increase returns quickly to the stream resulting in only a minimal change in irrigated area outflow timing and no change in outflow volume. The groundwater return component of the diversion increase returns very slowly to the stream resulting in a more significant change in outflow timing but no change in outflow volume. Outflows are reduced during the irrigation season

by the diversion of this water and increased during the nonirrigation season as it gradually returns to the stream system. Reservoir operations (energy production, flood control, etc.) are in turn impacted by these changes in the volume and timing of irrigated area outflow (Canyon Ferry inflow).

The effects of increases in the irrigated area were investigated by simulating the Canyon Ferry system's hydrologic behavior for three assumed irrigated acreage totals. All other system variables such as irrigated area inflow, irrigation efficiency, etc. were held constant so that the separate effects of the acreage changes (and proportionate consumptive use changes) might be assessed. Irrigated acreages of 658,900 (estimated current acreage (1)), 691,845, and 724,790 acres were considered in the simulations. The latter two acreages are respectively 105 and 110 percent of the first (current) acreage.

As before, simulation results were summarized in a series of graphs. Portions of these graphs (covering the period from 1969 through 1973) are shown in the following figures. Each of the graphs include four records: the historical record (Bureau of Reclamation) and one record for each of the three simulated acreage totals.

The first graph, Figure 23, shows how the Canyon Ferry inflow is affected by changes in irrigated area. Because the simulated hydrograph for the estimated current acreage is coincident with the historical hydrograph, only three hydrographs are evident in the figure. Although not terribly obvious from the figure, the reservoir inflow volumes (areas under the various hydrographs) are decreased as the irrigated acreage is increased and consumptive use is increased. Somewhat more obvious are the effects that the acreage changes have on the timing of reservoir inflows. Irrigation season inflows are reduced by the increased diversions required for the increased

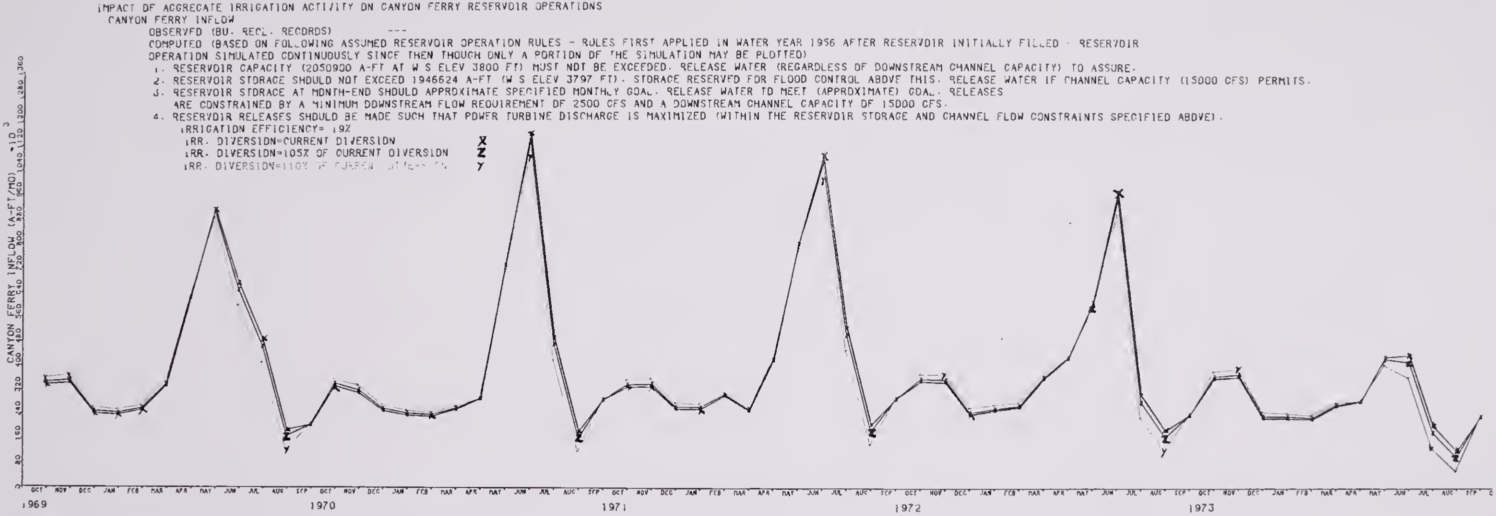

Figure 23. The effects of changes in irrigated area on Canyon Ferry inflow.

acreage and off-season inflows are increased by the groundwater return flows from those increased diversions.

The next four figure (24, 25, 26, and 27) illustrate how Canyon Ferry operations are impacted by the changes in irrigated acreage and the resultant changes in reservoir inflow. In these figures, the simulated records for the estimated current irrigated acreage (solid black lines) are not coincident with the historical records (dashed black lines). As discussed in detail in the section on the irrigation efficiency simulations, these differences result from the fact that the operations rules employed in the simulations necessarily deviate somewhat from those that were historically employed in the operation of the reservoir. The simulation rules never-the-less produce a reasonable simulation of historical reservoir operations (compare solid and dashed black lines). More importantly, the effects of changes in irrigated area are more apparent when viewed in the framework of a fixed set of reservoir operations rules (compare red, blue, and solid black lines).

Figure 24 shows how the month-end reservoir storage is affected by changes in irrigated acreage. Reservoir storage generally decreases in the summer months and increases in the winter months in response to the changes in reservoir inflows that result from changes in irrigated acreage. The decreased summer storages associated with the increased acreages require less frequent and less extensive use of flood control storage (above upper horizontal line). During the period from 1968 through 1984, it was necessary to use this storage during 6, 4, and 1 years in respective simulations of 100, 105, and 110 percent of the current estimated irrigated acreage. Figure 24 also shows that reservoir storage falls below that level at which head limits power production (middle horizontal line) less frequently as the irrigated area increases.

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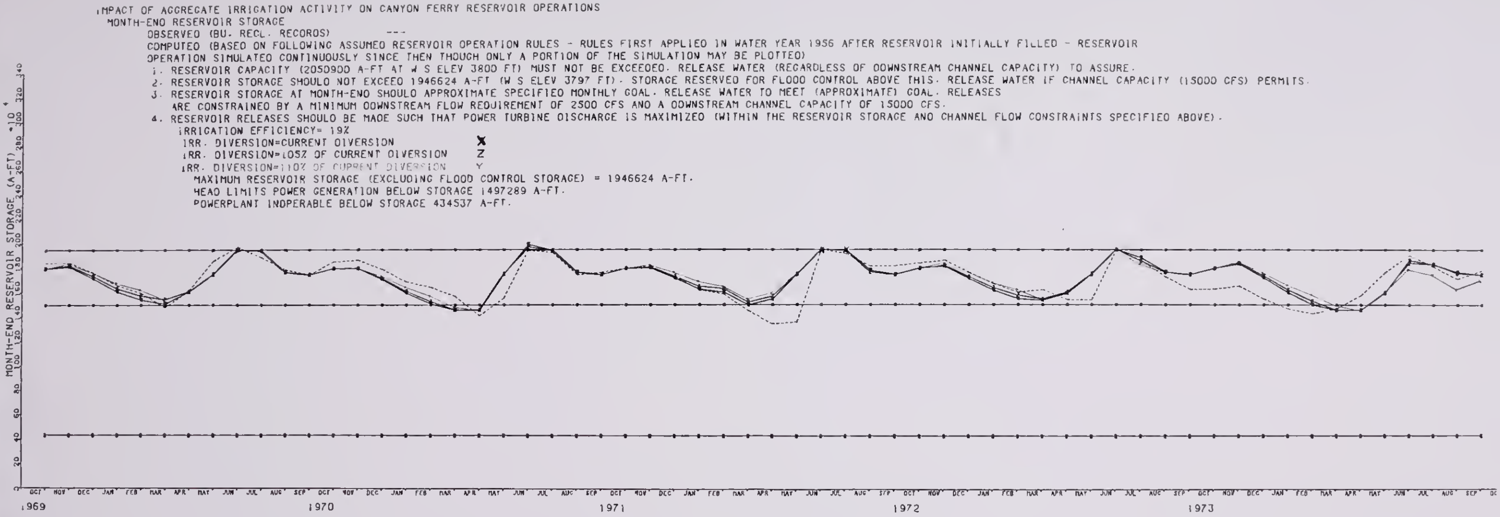

Figure 24. The effects of changes in irrigated area on Canyon Ferry month-end storage.

Figure 25 illustrates how the discharge below the dam (total reservoir release to the Missouri River) varies with changes in irrigated area. Although never exceeded during the 1969 through 1973 period, the channel capacity is more nearly approached when the smaller areas are irrigated. This is because a smaller portion of the spring irrigated area inflow is diverted to the smaller irrigated areas. Figure 25 also reveals that during the late summer months, the reservoir releases to the river are smaller when the larger areas are irrigated, and occasionally may fall to the minimum channel flow requirement of 2500 cfs (lower horizontal line). This is because the increased diversions required for the larger areas diminish reservoir inflow significantly during the low flow late summer months causing reservoir releases to be reduced via the reservoir operations rules. During the fall and winter, releases to the river are increased marginally when the larger areas are irrigated.

Figure 26 shows how the power turbine discharge is affected by changes in irrigated areas. It is little affected during late spring and early summer. Snowmelt runoff peaks at this time, and turbine discharge is limited by turbine capacity rather than reservoir inflow and storage regardless of the acreage irrigated. During late summer and early fall, the turbine discharge generally decreases with an increase in irrigated areas (and resultant decrease in reservoir inflow). During the late fall, winter, and early spring, there is a net increase in turbine discharge with an increase in the irrigated area. This increased discharge is made possible by the increased groundwater return flows from the larger areas. The off-season increases in turbine discharge occur in the late fall of each year and in the early spring of some years (1970 and 1973 of Figure 26). The time distribution of these increased releases are a consequence of the reservoir operations rules,

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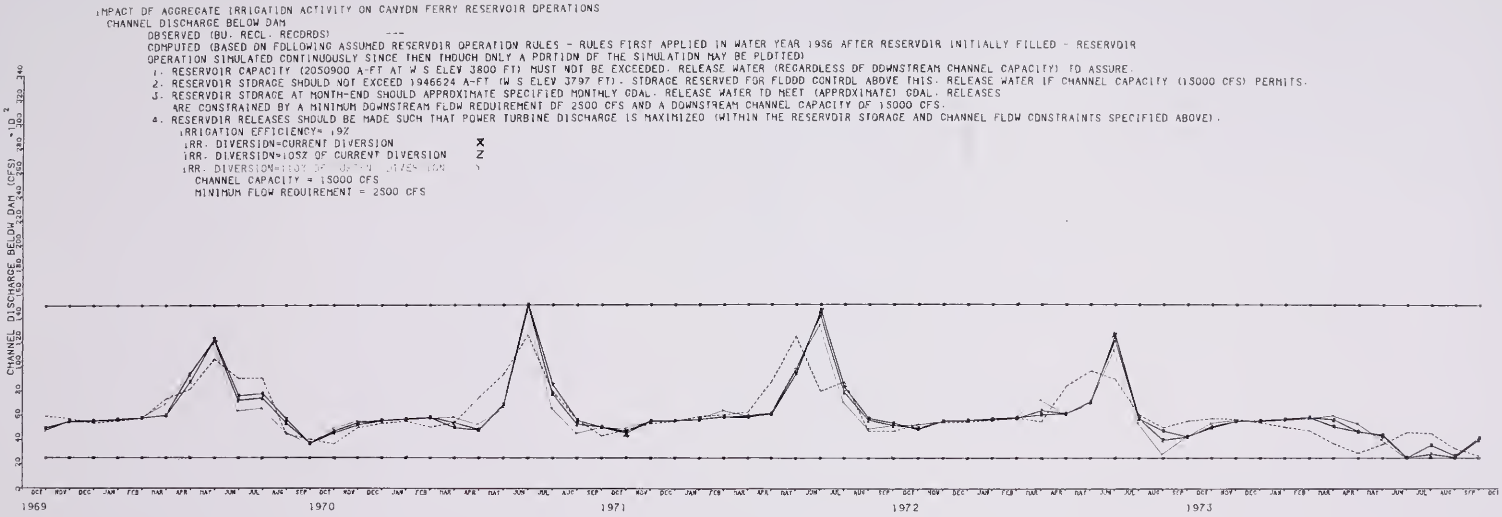

Figure 25. The effects of changes in irrigated area on Canyon Ferry releases to the Missouri River.

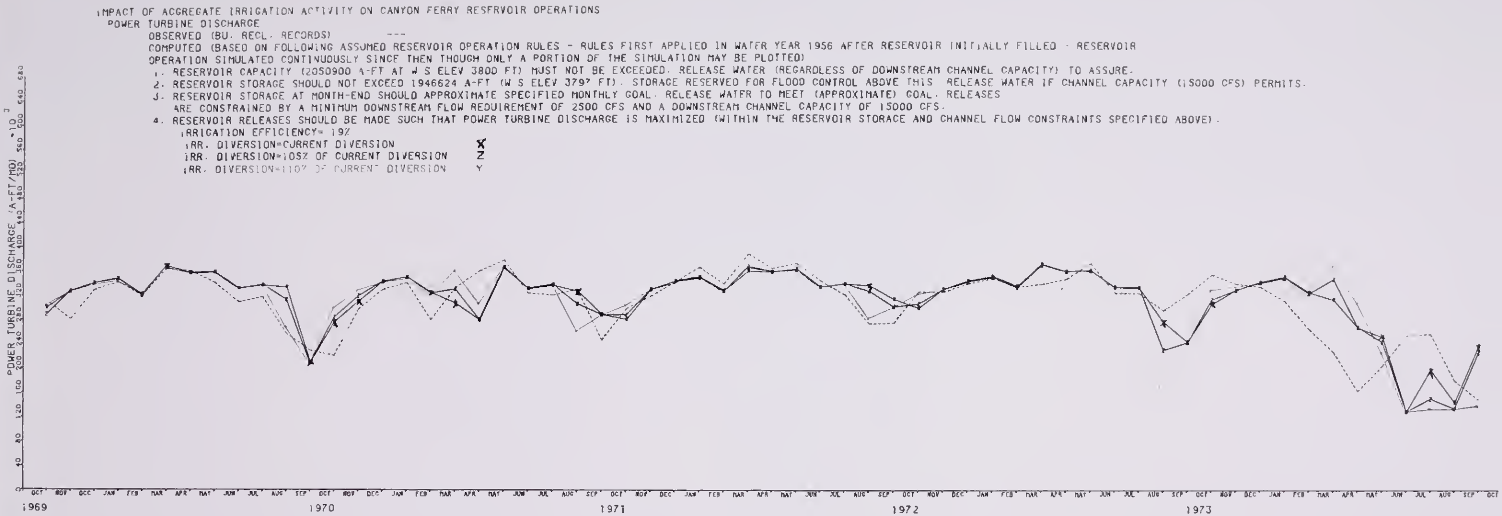

Figure 26. The effects of changes in irrigated area on Canyon Ferry power turbine discharge.

particularly the requirement that specified month-end storage goals be approximated. The increased turbine discharge could be released at any time during the winter with an appropriate change in the operations rules. Release during the high energy demand winter months would of course be advantageous.

Figure 27 demonstrates how energy production is affected by changes in irrigated area. Energy production is strongly, though not totally, dependent upon turbine discharge, and, as a consequence, the factors that affect turbine discharge similarly affect energy production. Energy production is largely unaffected by changes in irrigated area during the late spring and early fall when snowmelt runoff occurs and reservoir inflow is high. It generally decreases in the late summer and early fall when the increased diversions required for the larger areas diminish reservoir inflows, and increases during the late fall, winter and early spring when reservoir inflows are increased by the groundwater return flows derived from the earlier increased diversions.

Table 3 further illustrates the effects that changes in irrigated acreage have on energy production. The Table lists average monthly energy and production in millions of Kw-Hrs. It is based on simulations for the period from 1968 through 1984.

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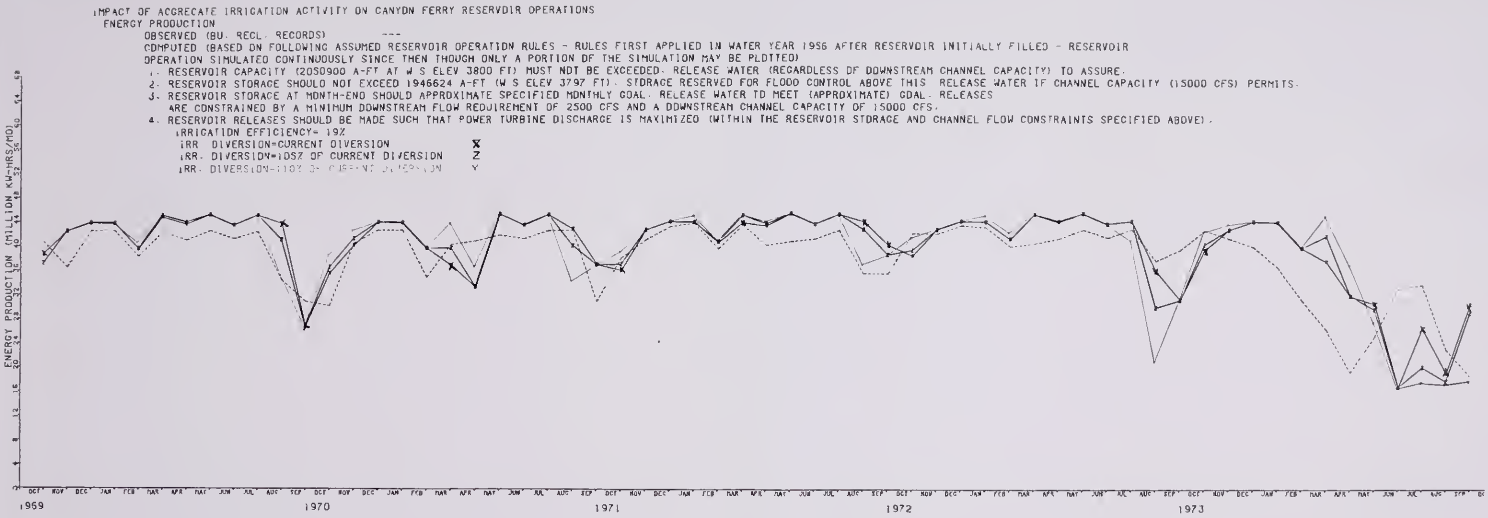

Figure 27. The effects of changes in irrigated area on Canyon Ferry energy production.

TABLE 3

Average Energy Production (Kw-Hr x 10^6) from 1968-1985

Month	Observed Bureau Reclamation	Simulated for Current Irr. Acreage	Simulated for 105% of Current Irr. Acreage	Simulated for 110% of Current Irr. Acreage
Oct	35.4	34.9	35.4	36.1
Nov	37.1	39.3	39.5	40.1
Dec	41.7	43.9	44.0	43.1
Jan	42.2	43.4	43.5	43.9
Feb	36.8	39.1	39.3	39.9
Mar	39.0	40.6	41.7	43.2
Apr	37.3	39.4	39.7	40.9
May	38.8	41.6	41.5	41.5
June	39.0	39.3	39.1	38.6
July	39.8	40.9	40.1	39.1
Aug	35.3	36.8	34.4	29.9
Sept	31.0	34.0	33.5	32.1
Annual	453.2	473.2	471.8	468.5

It can be seen that the average annual energy production (bottom of table) is decreased only slightly when the acreage irrigated is increased (from 473.2 x 10^6 Kw-Hrs for the current acreage to 468.5 x 10^6 Kw-Hrs for 110 percent of the current acreage). It can also be seen that the time distribution of energy production is changed somewhat when the irrigated acreage is changed. A comparison of the simulation results reveals that during the October through April off season, an average of 280.6 x 10^6 Kw-Hrs was produced when the current acreage was irrigated and an average of 287.2 x 10^6 Kw-Hrs was produced when 110 percent of the current acreage was irrigated.

TABLE 3

Average Energy Production (Kw-Hr x 10^6) from 1968-1985

Month	Observed Bureau Reclamation	Simulated for Current Irr. Acreage	Simulated for 105% of Current Irr. Acreage	Simulated for 110% of Current Irr. Acreage
Oct	35.4	34.9	35.4	36.1
Nov	37.1	39.3	39.5	40.1
Dec	41.7	43.9	44.0	43.1
Jan	42.2	43.4	43.5	43.9
Feb	36.8	39.1	39.3	39.9
Mar	39.0	40.6	41.7	43.2
Apr	37.3	39.4	39.7	40.9
May	38.8	41.6	41.5	41.5
June	39.0	39.3	39.1	38.6
July	39.8	40.9	40.1	39.1
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As evidenced by Figures 23 through 27 and by Table 3, it is concluded that increases in irrigated acreage have a minimal and not necessarily negative impact on Canyon Ferry operations.

SUMMARY

A methodology was developed to simulate the hydrologic behavior of the Canyon Ferry system. The methodology was utilized to investigate the impacts of changes in irrigation efficiency and of changes in irrigated acreage.

Improvements in irrigation efficiency, though advantageous to agricultural interests, were shown to be generally disadvantageous with regard to reservoir operations. Most importantly the potential for spring flooding is increased and the potential for energy production, particularly winter production, is decreased as irrigation efficiency is increased.

Increases in irrigated acreage, again advantageous to agricultural interests, were shown to have minimal and mixed impacts with regard to reservoir operations. On the negative side, annual energy production potential is reduced slightly as irrigated acreage is increased. On the positive side, spring flood potential is reduced slightly and winter energy production potential is increased slightly as the irrigated area is increased.

As detailed in earlier sections, numerous assumptions and idealizations were incorporated in the methodology. Though theoretically unappealing, they are a practical necessity. It would be impossible to simulate the behavior of a system as large and as diverse as the Canyon Ferry system without making numerous assumptions. Although the assumptions employed in this study are believed to be appropriate, it is recognized that they are somewhat subjective and that simulation results are dependent upon them. Never-the-less, it is believed that the impacts of irrigation activity changes identified in the study, though perhaps not precise, are never-the-less quantitatively reasonable and qualitatively valid. That is to say, the nature of the impacts would not be changed by reasonable changes in the assumptions.

Most of the effort expended to date in this investigation has been directed toward the development of a methodology for assessing the impacts of changes in irrigation activity. Many other things could and should be done to extend the usefulness of the study. The effects of combined changes in irrigation efficiency and irrigated acreage should be investigated since such combined changes are likely to occur. Some combination or combinations of these two changes may be most beneficial to the two major water users: agriculture and hydropower. The sensitivity of the simulation results to changes in assumptions relating to aquifer properties, irrigation operations, reservoir operations, etc. should be examined as well. The impacts of changes in irrigation activities on downstream energy producers should also be considered since these downstream users are very much dependent upon Canyon Ferry releases for their operation. Optimization studies could also be conducted to identify how available water might be best used to maximize the combined economic benefits to the agricultural and hydropower users. The methodology, which is quite general might also be applied at other western sites where agriculture and hydropower compete for a limited water resource.

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3. Hurley, P. A., "Predicting Return Flows from Irrigation," Journal Irrigation and Drainage, Proceedings American Society of Civil Engineers, 94(IR1), March, 1968.

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APPENDIX A

Table A-1 lists irrigation figures for the Canyon Ferry system. All values are from the Water Conservation and Salvage Report for Montana (1).

TABLE A-1
Upper (above Canyon Ferry) Missouri River
Irrigation Figures

County	Irrigated Area (10^3 Acres)	Crop Irr. Water Consumption (10^3 A-ft)	Irrigation Water Diversion (10^3 A-ft)
Beaverhead	329.0	323.6	1712.0
Broadwater	49.7	60.3	305.0
Deer Lodge	8.6	7.7	45.5
Gallatin	93.0	78.3	373.1
Jefferson	27.0	27.5	131.1
Madison	140.5	144.3	881.0
Meagher	6.5	6.2	42.0
Silverbow	4.6	3.4	13.7
Totals	658.9	651.3	3503.4

The fraction of the Meagher County Missouri River Basin irrigated acreage that drains into the Canyon Ferry Reservoir was estimated from the Atlas of Water Resources in Montana (4) to be 1/7. On the basis of the figures above the irrigation efficiency within the basin was estimated to be

$$\text{Irrigation Efficiency} = \frac{651.3}{3503.9} \times 100\% \cong 19\%$$

Records of irrigation diversions at several sites in the Upper Missouri River Basin were examined to determine diversion timing. The diversion records are summarized in Table A-2 below.

TABLE A-2

Average Monthly Irrigation Diversions
May Through September

	Helena Valley From Canyon Ferry (1959-81)		East Bench Full Service Near Dillon (1966-73)		East Bench Supplemental Near Dillon (1965-73)	
Month	Volume Diverted (acre-ft)	Percent of Total	Volume Diverted (acre-ft)	Percent of total	Volume Diverted (acre-ft	Percent of total
May	11620	17.7	11293	13.4	23085	11.7
June	14940	22.8	18933	22.4	55566	28.1
July	17064	26.0	22017	26.1	45072	22.8
Aug	15288	23.3	20104	23.8	47493	24.0
Sept	6658	10.2	12077	14.3	26486	13.4
Totals:	65570	100.0	84424	100.0	197702	100.0

These records were assumed to be representative of irrigation timing throughout the basin (records are generally not available for most diversions). On the basis of these records, it was assumed that 25 percent of the total annual diversion occurs in each of the three months of June, July, and August, while 10 percent occurs in each of the months of May and September, and 2 1/2 percent occurs in April and October (although limited diversions are sometimes made in April and October, incomplete records made it necessary to estimate the diversions during these months).

Table A-3 lists the total basin-wide diversions by month. It also lists the crop consumptive use by month (assuming an irrigation efficiency of 19 percent).

TABLE A-3

Monthly Irrigation Figures for Canyon Ferry Catchment

Month	Percent of Annual Diversion	Diversion (Acre-ft)	Crop Irr. Water Consumption (Acre-ft)
Apr	2.5	87,585	16,282
May	10.0	350,340	65,130
June	25.0	875,850	162,825
July	25.0	875,850	162,825
Aug	25.0	875,850	162,825
Sept	10.0	350,340	65,130
Oct	2.5	87,585	16,282
Annual Totals	100	3,503,400	651,300

APPENDIX B

Aquifer transmissivity values determined by USGS well tests in the Gallatin Valley (5) are shown in Tables B-1 and B-2. These values were used to estimate the average tansmissivity in the Canyon Ferry drainage.

TABLE B-1

Transmissivity Values for
Wells Located on the Alluvial Plain

Township	Range	Section	Location in Sections	Transmissivity (gal/day/ft)
2S	4E	26	dc	380,000
3S	4E	11	bdb	170,000
1N	4E	28	da	280,000
1S	4E	1	cb	670,000
1S	4E	1	dc	240,000
1S	4E	2	dd	130,000
1S	4E	9	cb	140,000
1S	4E	15	ab	94,000
1S	5E	5	ad	130,000
1S	5E	9	cd	50,000
1S	5E	30	cb	290,000
2S	4E	11	dc	270,000
2S	4E	14	ada	260,000
2S	4E	14	bb	70,000
1N	4E	5	da	100,000
1N	4E	5	dd	110,000
1N	4E	6	bc	38,000
1N	4E	19	cb	480,000
1N	4E	19	cb	180,000
1N	4E	22	dc	480,000
1N	3E	4	ad	140,000
1N	3E	10	bd	140,000
1N	3E	10	ca	130,000
1N	3E	22	da	120,000
				Ave = 212,170

TABLE B-2

Transmissivity Values for
Wells Located on the Bozeman Fan

Township	Range	Section	Location in Sections	Transmissivity (gal/day/ft)
1S	5E	26	da	64,000
2S	5E	11	dcc	4,500
2S	5E	11	dcc	36,000
2S	5E	15	aa	26,000
2S	5E	27	cc	50,000
2S	5E	35	dc	65,000
			Ave =	40,917

APPENDIX C

As described in the report, groundwater return flow factors were calculated for the Canyon Ferry system. Table C-1 on the following page summarized these calculations.

TABLE C-1

Groundwater Return Flow Factors for the Canyon Ferry Drainage

$$\alpha = \frac{T}{S} = \frac{120{,}000 \text{ gal/day/ft}}{.20} \times \frac{1 \text{ ft}^3}{7.48 \text{ gal}} = 80{,}213.90 \text{ ft}^2\text{/day}$$

$$\frac{\alpha t}{L^2} = \frac{(80213.9 \text{ ft}^2\text{/day})\ 30.4 \text{ days}}{(2 \text{ mi} \times 5280 \text{ ft/mi})^2} = .0218673$$

Month	$\frac{\alpha t}{L^2}$	R	R x Month	First Diff.	Return Flow Factor Second Diff.
0	.0	.0	.0		
1	.0218673	.2224734	.2224734	.2224734	.22247
2	.0437346	.3146052	.6292104	.4067370	.18426
3	.0656019	.3849690	1.1549069	.5256965	.11896
4	.0874692	.4433043	1.7732171	.6183102	.09261
5	.1093366	.4931402	2.4657012	.6924841	.07417
6	.1312039	.5363153	3.2178921	.7521909	.05971
7	.1530712	.5740272	4.0181906	.8002985	.04811
8	.1749385	.6071568	4.8572541	.8393635	.03907
9	.1968058	.6363950	5.7275547	.8703006	.03094
10	.2186731	.6623034	6.6230335	.8954788	.02518
11	.2405404	.6853458	7.5388036	.9157701	.02029
12	.2624077	.7059104	8.4709246	.9321210	.01635
13	.2842751	.7243250	9.4162249	.9453003	.01318
14	.3061424	.7408674	10.3721434	.9559185	.01062
15	.3280097	.7557747	11.3366200	.9644766	.00856
16	.3498770	.7692493	12.3079884	.9713684	.00689
17	.3717443	.7814656	13.2849146	.9769262	.00556
18	.3936116	.7925734	14.2663206	.9814060	.00448
19	.4154789	.8027019	15.2513364	.9850158	.00361
20	.4373462	.8111963	16.2392622	.9879258	.00291
21	.4592136	.8204540	17.2295335	.9902713	.00235
22	.4810809	.8282588	18.2216925	.9921590	.00189
23	.5029482	.8354510	19.2153731	.9936806	.00152
24	.5248155	.8420949	20.2102784	.9949053	.00122
25	.5466828	.8482469	21.2061735	.9958951	.00099
26	.5685501	.8539564	22.2028654	.9966919	.00080
27	.5904174	.8592667	23.2001997	.9973343	.00064
28	.6122847	.8642162	24.1980530	.9978533	.00052
29	.6341520	.8688387	25.1963230	.9982700	.00042
30	.6560194	.8731643	26.1949292	.9986062	.00034
31	.6778867	.8772194	27.1938023	.9988731	.00027
32	.6997540	.8810280	28.1928968	.9990945	.00022
33	.7216213	.8846111	29.1921659	.9992691	.00017
34	.7434886	.8879876	30.1915781	.9994122	.00014
35	.7653559	.8911744	31.1911038	.9995257	.00011
36	.7872232	.8941867	32.1907207	.9996159	.00009

Note that the return flow factor (the percentage of a given month's irrigation groundwater recharge that returns in a specified month decreases with time. After 36 months, 99.96 percent of a given month's recharge has returned to the surface water system. Return flow in subsequent months is assumed to be zero.

APPENDIX D

Canyon Ferry Operations Record

This appendix contains the Bureau of Reclamation's monthly reservoir operation records for the period from 1955 through 1984.

PROGRAM RES070

RESERVOIR RECORDS STORAGE SYSTEM
MONTHLY RESERVOIR OPERATION RECORD

DATE RUN% DEC 18, 1984
PAGE 050

CF - CANYON FERRY RESERVOIR

CF10 - MIDNIGHT RESERVOIR ELEVATION

UNITS% FEET

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	DAILY MINIMUM (FEET)	DAILY MAXIMUM (FEET)
1955	3781.94	3782.31	3779.42	3776.51	3773.21	3771.44	3774.39	3782.77	3796.10	3800.00	3797.10	3794.79	3771.17	3800.00
1956	3792.69	3791.85	3790.29	3788.04	3784.09	3785.94	3787.72	3796.03	3799.91	3797.95	3794.15	3791.91	3782.37	3800.00
1957	3791.06	3792.84	3791.09	3786.15	3782.83	3781.26	3782.49	3794.90	3799.08	3797.08	3792.91	3791.00	3781.18	3799.23
1958	3791.70	3793.61	3792.18	3788.21	3785.71	3786.45	3784.23	3790.85	3798.88	3796.94	3793.24	3790.00	3784.02	3798.90
1959	3789.48	3790.73	3790.90	3789.78	3789.38	3792.03	3796.49	3795.10	3799.40	3798.95	3797.08	3798.23	3789.12	3799.88
1960	3799.66	3797.32	3790.83	3792.00	3794.20	3796.88	3797.02	3796.89	3798.00	3794.52	3791.47	3788.54	3788.54	3799.94
1961	3785.93	3785.28	3784.98	3782.38	3782.79	3783.43	3780.98	3781.84	3787.05	3782.50	3775.63	3775.22	3774.57	3788.43
1962	3779.45	3782.02	3779.24	3775.66	3775.82	3772.94	3780.55	3792.20	3798.94	3799.88	3797.18	3796.76	3772.75	3800.00
1963	3797.97	3798.93	3799.18	3797.26	3797.92	3797.60	3798.28	3798.66	3799.04	3797.56	3794.19	3793.43	3793.40	3799.70
1964	3793.13	3793.96	3791.60	3790.77	3790.92	3790.61	3791.04	3794.30	3799.73	3799.39	3797.04	3796.83	3790.19	3800.00
1965	3797.34	3797.59	3795.23	3793.81	3791.75	3788.04	3786.31	3786.75	3799.00	3799.54	3799.76	3798.76	3785.58	3799.93
1966	3792.60	3790.73	3787.96	3785.60	3785.06	3783.57	3782.60	3784.30	3786.38	3783.88	3778.93	3777.51	3777.50	3798.58
1967	3781.03	3785.54	3782.00	3776.54	3771.10	3765.19	3765.12	3778.03	3798.26	3796.13	3791.18	3790.11	3764.70	3798.30
1968	3792.42	3795.67	3793.18	3790.11	3788.67	3780.98	3777.95	3779.76	3796.45	3794.82	3793.18	3794.73	3777.83	3797.17
1969	3793.87	3793.96	3791.39	3788.22	3786.19	3782.30	3786.76	3794.30	3797.63	3795.15	3792.15	3790.88	3780.62	3797.64
1970	3794.10	3794.53	3792.25	3789.11	3787.69	3785.29	3779.95	3784.77	3796.82	3796.26	3790.88	3791.50	3778.13	3797.14
1971	3792.51	3792.92	3790.40	3787.06	3785.91	3781.45	3777.60	3778.18	3797.09	3796.03	3792.98	3793.12	3776.93	3797.47
1972	3793.82	3794.44	3791.50	3788.63	3786.46	3787.11	3784.46	3784.39	3797.06	3794.43	3790.36	3787.21	3781.91	3797.34
1973	3787.28	3788.06	3784.67	3781.94	3780.60	3782.06	3785.52	3791.48	3795.70	3792.92	3789.89	3791.94	3780.56	3796.55
1974	3793.46	3794.39	3792.06	3788.69	3785.86	3782.75	3783.70	3787.19	3797.80	3794.46	3790.72	3788.80	3781.76	3798.74
1975	3789.66	3791.30	3789.43	3784.80	3781.08	3777.13	3775.09	3784.04	3799.22	3797.60	3796.94	3796.11	3774.78	3799.96
1976	3797.50	3795.77	3794.00	3792.07	3789.60	3785.08	3781.62	3791.29	3797.56	3796.61	3793.32	3792.97	3781.05	3798.25
1977	3795.83	3797.05	3795.48	3792.08	3790.66	3789.84	3790.96	3791.03	3796.02	3794.41	3791.16	3792.48	3789.75	3797.09
1978	3794.63	3794.56	3791.46	3787.42	3783.04	3781.63	3783.83	3789.94	3797.02	3796.35	3791.26	3791.11	3780.69	3797.95
1979	3792.68	3791.41	3787.84	3782.11	3779.46	3780.04	3782.45	3790.84	3796.00	3793.45	3790.37	3788.36	3779.25	3796.24
1980	3788.12	3789.79	3788.05	3783.24	3782.39	3782.69	3786.14	3798.00	3797.96	3794.55	3791.13	3794.13	3781.84	3799.23
1981	3794.74	3795.08	3793.43	3790.34	3787.02	3785.65	3785.09	3799.07	3797.08	3793.85	3789.97	3788.05	3784.23	3799.70
1982	3791.39	3792.98	3791.27	3786.32	3784.27	3781.18	3780.07	3787.59	3798.48	3797.44	3792.54	3792.96	3779.66	3798.81
1983	3793.99	3794.85	3793.28	3791.73	3789.29	3787.24	3785.62	3789.03	3797.76	3797.21	3794.03	3794.90	3785.08	3798.29
1984	3796.84	3795.96	3792.42	3790.55	3788.15	3785.82	3786.12	3792.91	3799.13	3797.13	3793.65	3787.16	3785.00	3799.14
AVE.	3791.89	3792.51	3790.23	3787.24	3785.37	3783.79	3784.01	3789.55	3797.15	3795.57	3792.15	3791.32	3781.14	3798.32

RESERVOIR RECOROS STORAGE SYSTEM
MONTHLY RESERVOIR OPERATION RECORD

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CF - CANYON FERRY RESERVOIR   CF20 - MIDNIGHT TOTAL RESERVOIR STORAGE   UNITS% AF

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	DAILY MINIMUM (AF)	DAILY MAXIMUM (AF)
1955	1469079.	1480309.	1394963.	1318518.	1231827.	1185329.	1262825.	1494270.	1919392.	2050900.	1953112.	1875219.	1178236.	2050900.
1956	1804407.	1776082.	1723479.	1654214.	1534332.	1590479.	1644502.	1917032.	2047865.	1981774.	1853638.	1778105.	1482130.	2050900.
1957	1749443.	1809465.	1750455.	1596853.	1496091.	1448441.	1485772.	1878928.	2019878.	1952438.	1811825.	1747420.	1446013.	2024936.
1958	1771024.	1835429.	1787210.	1659374.	1583499.	1605958.	1538581.	1742362.	2013134.	1947717.	1822953.	1713700.	1532207.	2013808.
1959	1697918.	1738316.	1744048.	1707023.	1694883.	1782152.	1932543.	1885672.	2030668.	2015494.	1952438.	1991216.	1686992.	2046854.
1960	2039435.	1960530.	1741688.	1781140.	1855324.	1945694.	1950414.	1946031.	1983460.	1866114.	1763268.	1669389.	1669389.	2048877.
1961	1590176.	1570448.	1561343.	1482433.	1494877.	1514301.	1439943.	1466044.	1624168.	1486075.	1295400.	1284629.	1267554.	1666051.
1962	1395752.	1471507.	1390235.	1296188.	1300391.	1224734.	1426893.	1787884.	2015157.	2046854.	1955810.	1941647.	1219743.	2050900.
1963	1982448.	2014820.	2023250.	1958507.	1980762.	1969972.	1992902.	2005715.	2018529.	1968623.	1854987.	1829360.	1828348.	2040784.
1964	1819244.	1847231.	1767652.	1739664.	1744722.	1734269.	1748769.	1858696.	2041796.	2029529.	1948003.	1940811.	1720107.	2050900.
1965	1958348.	1966968.	1886328.	1838609.	1770509.	1651343.	1597446.	1611056.	2015866.	2034784.	2042492.	2007523.	1575021.	2048448.
1966	1798455.	1737294.	1648825.	1575632.	1559128.	1514282.	1485519.	1536160.	1599611.	1523524.	1380171.	1341059.	1340786.	2001266.
1967	1439702.	1573799.	1467863.	1314785.	1174446.	1035524.	1033952.	1355256.	1990143.	1916875.	1751898.	1717255.	1024633.	1991533.
1968	1792520.	1901243.	1817637.	1717255.	1671275.	1438258.	1353061.	1403458.	1927817.	1872484.	1817637.	1869460.	1349788.	1952486.
1969	1840606.	1843602.	1758755.	1657038.	1593735.	1476691.	1611365.	1855013.	1968347.	1883616.	1783617.	1742142.	1429383.	1968692.
1970	1848294.	1862740.	1786915.	1685234.	1640377.	1566158.	1408795.	1550350.	1940469.	1921320.	1742142.	1762346.	1358024.	1951451.
1971	1795488.	1809007.	1726628.	1620665.	1585107.	1451895.	1343514.	1359408.	1949727.	1913456.	1810986.	1815640.	1325266.	1962830.
1972	1838942.	1859717.	1762346.	1670010.	1602088.	1622230.	1540990.	1538877.	1948693.	1859381.	1725336.	1625359.	1465250.	1958348.
1973	1627549.	1651975.	1547331.	1466121.	1427379.	1469629.	1573187.	1761693.	1902260.	1809007.	1710182.	1776712.	1426233.	1931237.
1974	1826958.	1858037.	1780649.	1671908.	1583579.	1489933.	1518158.	1624733.	1974209.	1860389.	1736971.	1675388.	1460895.	2006828.
1975	1702825.	1755816.	1695469.	1551256.	1441154.	1330693.	1276188.	1528310.	2023573.	1967313.	1944572.	1916191.	1268072.	2049499.
1976	1963865.	1904633.	1844934.	1780979.	1700906.	1559739.	1456831.	1755490.	1965933.	1933288.	1822297.	1810656.	1440283.	1989795.
1977	1906667.	1948348.	1894803.	1781309.	1735032.	1708583.	1744728.	1747001.	1913114.	1858709.	1751245.	1794499.	1705704.	1949727.
1978	1866100.	1863748.	1761040.	1631929.	1498482.	1457121.	1522034.	1711781.	1947314.	1924398.	1754510.	1749613.	1429955.	1979381.
1979	1801093.	1759408.	1645071.	1471100.	1395031.	1411345.	1481105.	1740850.	1912430.	1826625.	1725659.	1661467.	1389132.	1920637.
1980	1653874.	1706983.	1651659.	1504444.	1479339.	1488167.	1592188.	1981105.	1979726.	1863412.	1750266.	1849302.	1463218.	2023924.
1981	1869796.	1881243.	1825959.	1724689.	1619414.	1577161.	1560045.	2018318.	1949382.	1839941.	1712740.	1651975.	1534046.	2040390.
1982	1758755.	1810986.	1754837.	1597756.	1535254.	1444057.	1412204.	1637249.	1997790.	1961796.	1796477.	1810326.	1400649.	2009261.
1983	1844601.	1873491.	1820966.	1769856.	1690991.	1626297.	1576244.	1682676.	1972830.	1953865.	1845942.	1875171.	1559739.	1990838.
1984	1941153.	1911074.	1792520.	1731477.	1654823.	1582356.	1591570.	1808677.	2020420.	1951107.	1833283.	1623794.	1557294.	2020771.
AVE.	1779817.	1799475.	1725162.	1631866.	1575825.	1530093.	1536742.	1706337.	1953790.	1900694.	1788329.	1761579.	1451136.	1993075.

RESERVOIR RECORDS STORAGE SYSTEM
MONTHLY RESERVOIR OPERATION RECORD

CF - CANYON FERRY RESERVOIR   CF31 - COMPUTED NET INFLOW (MONTHLY)   UNITS% AF

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	DAILY MINIMUM (CFS)	DAILY MAXIMUM (CFS)
1955	244792.	270010.	198589.	184661.	158824.	193648.	242005.	351893.	509359.	344475.	115136.	148292.	759.	14498.
1956	209157.	247466.	243025.	228341.	176616.	324000.	428322.	802474.	678845.	183868.	130453.	169212.	710.	27110.
1957	232205.	306188.	210270.	150811.	190877.	242973.	264157.	584386.	796605.	255175.	110340.	181924.	290.	18300.
1958	286036.	307577.	243808.	207021.	217825.	238241.	296852.	585524.	527157.	254874.	134678.	160939.	1370.	14804.
1959	260993.	278075.	239762.	194826.	176688.	253531.	285189.	352958.	774152.	306984.	103557.	153183.	710.	19050.
1960	413615.	470082.	471112.	230757.	239427.	365216.	441877.	481983.	436344.	105183.	105759.	144817.	740.	13330.
1961	186044.	226522.	209853.	194457.	205573.	199107.	153911.	198593.	301751.	79398.	69786.	175142.	148.	9468.
1962	310185.	330470.	192565.	169458.	213086.	244475.	386233.	490974.	689264.	276238.	174030.	215923.	584.	15550.
1963	290084.	312734.	246567.	174036.	291669.	231352.	237203.	495530.	897441.	283597.	114208.	217470.	1040.	17450.
1964	258069.	300218.	211299.	206896.	205168.	221456.	251504.	541707.	1152640.	468113.	163876.	226939.	1170.	24370.
1965	259005.	299734.	234282.	265610.	224644.	248660.	436121.	687197.	1116428.	653032.	254773.	311922.	166.	23109.
1966	405909.	413589.	267271.	240335.	229347.	263089.	282811.	273209.	253347.	125891.	75584.	127047.	442.	8188.
1967	265178.	302037.	207630.	209720.	190471.	202155.	221746.	562219.	1220358.	479508.	146592.	203074.	1653.	24516.
1968	309834.	311536.	227938.	228339.	272687.	319119.	308386.	450323.	1014146.	352490.	236642.	310588.	1243.	21739.
1969	337757.	342986.	243451.	238947.	254803.	333251.	621217.	909673.	669566.	483804.	189168.	205908.	821.	19033.
1970	331737.	308975.	251333.	236703.	232871.	255340.	290412.	725393.	1155078.	490147.	183219.	287484.	1137.	26906.
1971	328758.	329567.	256518.	256998.	300270.	251325.	417015.	793810.	1080263.	520669.	205747.	290953.	2535.	22441.
1972	346350.	342845.	238449.	252133.	262818.	355632.	423374.	603836.	962120.	302192.	186587.	237830.	1159.	23783.
1973	355432.	360920.	226736.	227183.	223916.	267594.	282807.	427283.	433571.	203974.	121027.	234176.	1056.	11770.
1974	298756.	329849.	249310.	231328.	229630.	274881.	406474.	558053.	1042726.	336650.	192210.	206503.	821.	27570.
1975	295289.	264791.	250018.	211749.	195814.	257437.	298024.	634339.	1185853.	923198.	375998.	291991.	1984.	25866.
1976	407575.	399784.	371845.	304972.	265053.	329133.	542927.	1130310.	926580.	409874.	250673.	322611.	1391.	23964.
1977	411741.	365704.	277914.	218007.	219766.	224537.	288133.	214369.	320707.	117993.	99195.	195584.	1100.	10273.
1978	292488.	267415.	237044.	222307.	223305.	358982.	445926.	618819.	717005.	446112.	169446.	289577.	1313.	16372.
1979	318835.	275173.	229997.	191205.	210964.	335934.	390765.	612607.	477510.	157234.	135826.	152424.	1458.	17405.
1980	197537.	250287.	217581.	171350.	221262.	246825.	348028.	702208.	829457.	312333.	137782.	269655.	1038.	19736.
1981	297035.	313725.	268816.	237528.	213808.	243524.	280229.	861740.	1108833.	273590.	131032.	138577.	1267.	30800.
1982	288470.	287990.	249187.	196395.	259835.	289632.	364233.	746761.	1143837.	657092.	201647.	290390.	2034.	25674.
1983	362582.	351879.	282143.	290842.	249901.	318143.	344104.	507709.	776499.	616403.	255761.	302493.	2560.	18560.
1984	410259.	427331.	280443.	324936.	283263.	314378.	396248.	805009.	1189757.	608681.	364276.	364550.	1834.	26148.
AVE.	307057.	319849.	251159.	223262.	228006.	273452.	345874.	590363.	812907.	367626.	171167.	227573.	1151.	19926.

PROGRAM RESO71

RESERVOIR RECORDS STORAGE SYSTEM
MONTHLY RESERVOIR OPERATION RECORD

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CF - CANYON FERRY RESERVOIR

CF31 - COMPUTED NET INFLOW (MONTHLY)

UNITS AF

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL TOTAL (AF)
1955	244792.	270010.	198589.	194651.	158824.	193648.	242005.	351893.	509359.	344475.	115136.	148292.	2951684.
1956	237157.	247456.	243025.	228341.	176616.	324000.	429322.	932474.	678845.	193868.	130453.	165212.	3921779.
1957	232205.	305139.	210270.	150811.	190977.	242973.	254157.	594386.	795605.	255175.	110340.	181924.	3525911.
1958	286036.	307577.	243908.	207021.	217825.	238241.	296952.	585524.	527157.	254874.	134676.	160939.	3460532.
1959	260793.	278075.	239752.	194926.	176688.	253531.	295187.	352958.	774152.	306984.	103557.	153183.	3379898.
1960	413515.	470082.	471112.	230757.	239427.	355215.	441977.	491993.	436344.	105183.	105759.	144817.	3906172.
1961	186044.	225522.	207853.	194457.	205573.	199107.	153911.	198593.	301751.	79396.	59786.	175142.	2200137.
1962	310185.	330470.	192565.	169456.	213086.	244475.	386233.	490974.	699264.	276238.	174030.	215923.	3692901.
1963	290094.	312734.	246567.	174036.	291659.	231352.	237203.	495530.	897441.	293597.	114208.	217470.	3791891.
1964	259369.	300218.	211299.	206896.	205168.	221456.	251594.	541707.	1152540.	458113.	153876.	226935.	4207885.
1965	259005.	299734.	234232.	265510.	224544.	248660.	436121.	687197.	1116426.	653032.	254773.	311922.	4971409.
1966	405907.	413587.	247271.	240335.	229347.	263089.	292811.	273209.	253347.	125891.	75584.	127047.	2957429.
1967	255179.	392037.	297530.	209720.	190471.	202155.	221745.	552219.	1220358.	479508.	146592.	202074.	4210682.
1968	309934.	311535.	227939.	228339.	272687.	319119.	308336.	450323.	1014146.	352490.	236642.	310588.	4342028.
1969	337757.	342995.	243451.	238947.	254803.	333251.	621217.	909573.	669566.	483804.	189158.	205909.	4930531.
1970	331737.	308975.	251333.	236703.	232871.	255340.	290412.	725393.	1155078.	490147.	193219.	287484.	4748692.
1971	328758.	329567.	254516.	256939.	300270.	251325.	417015.	793810.	1080263.	520569.	205747.	290953.	5031993.
1972	346350.	342845.	239449.	252133.	252818.	355532.	423374.	603936.	962120.	302192.	196587.	237839.	4514166.
1973	355432.	350720.	226735.	227183.	223916.	267594.	282807.	427283.	433571.	203974.	121027.	234176.	3364619.
1974	298756.	329849.	249310.	231328.	229530.	274881.	406474.	558053.	1042726.	336650.	192210.	206503.	4356370.
1975	295293.	264791.	250018.	211749.	195814.	257437.	298024.	634339.	1185853.	923198.	375998.	291991.	5184501.
1976	407575.	397784.	371845.	304972.	255053.	329133.	542927.	1130310.	925580.	409874.	250673.	322611.	5651337.
1977	411741.	365704.	277914.	218007.	219766.	224537.	298133.	214359.	320707.	117993.	99195.	195584.	2953650.
1978	272488.	267415.	237044.	222307.	223305.	358992.	445926.	618819.	717005.	446112.	159446.	209577.	4289426.
1979	319335.	275173.	229997.	191205.	210954.	335934.	390765.	612607.	477510.	157234.	135826.	152424.	3489474.
1980	197537.	250287.	217591.	171350.	221262.	246825.	349028.	792208.	829457.	312333.	137792.	263655.	3904305.
1981	297035.	313725.	259816.	237526.	213908.	243524.	290229.	861740.	1109933.	273590.	131032.	138577.	4369437.
1982	289470.	287970.	249197.	196395.	259835.	289532.	364233.	746761.	1143837.	657092.	201647.	290390.	4575469.
1983	362582.	351879.	222143.	290942.	249901.	318143.	344104.	507709.	776499.	616403.	255761.	302493.	4658459.
1984	410259.	427331.	290443.	324936.	283263.	314378.	396248.	905009.	1189757.	608681.	364276.	364550.	5769131.
AVE.	307057.	319849.	251159.	223262.	228006.	273452.	345874.	590363.	812907.	367626.	171167.	227573.	4118293.

RESERVOIR RECORDS STORAGE SYSTEM
MONTHLY RESERVOIR OPERATION RECORD

CF - CANYON FERRY RESERVOIR   CF40 - TOTAL RESERVOIR DISCHARGE   UNITS% AF

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	DAILY MINIMUM (CFS)	DAILY MAXIMUM (CFS)
1955	188346.	258781.	283928.	261104.	245514.	240143.	164503.	120444.	84226.	212969.	212922.	226183.	260.	6626.
1956	279967.	275788.	295626.	297600.	296489.	267848.	374301.	529944.	548013.	249957.	258585.	244742.	430.	24030.
1957	260868.	246168.	269276.	304403.	291630.	290618.	226830.	191226.	655656.	322611.	250949.	246327.	970.	17110.
1958	262433.	243173.	292026.	334849.	293692.	215782.	364225.	381739.	256383.	320291.	259438.	270188.	0.	8410.
1959	276773.	237679.	234030.	231848.	188826.	166264.	134797.	399828.	629157.	322155.	166611.	114407.	290.	18210.
1960	365395.	548985.	689950.	191306.	165243.	274849.	437157.	486367.	398915.	222525.	208602.	238691.	840.	15810.
1961	265249.	246248.	218955.	273362.	193130.	179683.	228258.	172483.	143623.	217487.	260449.	185911.	190.	5950.
1962	199061.	254717.	273838.	263504.	208879.	320132.	184066.	129977.	461990.	244542.	265071.	230083.	220.	13170.
1963	249283.	280363.	238135.	238776.	269415.	242142.	214274.	482717.	884628.	333501.	227841.	243094.	590.	15130.
1964	268185.	272231.	290876.	234883.	200112.	231907.	250215.	431782.	969540.	480377.	245395.	234129.	1450.	24370.
1965	241468.	291114.	314916.	313329.	292740.	367815.	490016.	673586.	711610.	634115.	247061.	346889.	260.	17970.
1966	614975.	474744.	355735.	313527.	245851.	307934.	311563.	222565.	189897.	201977.	218935.	166155.	1240.	10030.
1967	166532.	167940.	313567.	362796.	330803.	341078.	223319.	240912.	585461.	552773.	311563.	237719.	2430.	17090.
1968	234565.	202810.	311544.	328720.	318684.	552139.	393580.	399927.	489778.	407821.	291491.	258763.	0.	11000.
1969	366605.	339987.	328304.	340661.	318099.	450297.	486535.	666019.	556234.	568532.	289160.	247378.	3710.	15000.
1970	225580.	294525.	327154.	338380.	277725.	329554.	447772.	583834.	764945.	509296.	362400.	267273.	2810.	15000.
1971	295616.	316046.	338896.	362955.	335821.	384535.	525399.	777917.	489937.	556939.	308211.	286294.	3580.	15000.
1972	323048.	322076.	335821.	344469.	330744.	335484.	504611.	605950.	552297.	391497.	320628.	337805.	3580.	12000.
1973	353236.	336496.	331378.	308390.	262651.	225342.	179246.	238770.	292998.	297223.	219848.	167643.	60.	6270.
1974	248509.	298770.	326697.	340066.	317950.	368529.	378248.	451477.	693243.	450466.	315630.	268086.	2940.	17000.
1975	267848.	211795.	310354.	355954.	305911.	367894.	352522.	382215.	690585.	979457.	398737.	320370.	3460.	22000.
1976	359901.	459015.	431544.	368925.	345124.	470301.	645838.	831649.	716132.	442512.	361666.	334254.	5250.	15000.
1977	315729.	324020.	331458.	331497.	266043.	250988.	251980.	212092.	154592.	172403.	206658.	152330.	2370.	6000.
1978	220879.	269772.	339749.	351411.	356747.	400344.	381005.	429064.	481468.	469031.	339332.	294466.	2360.	9910.
1979	267352.	316859.	344330.	365177.	287028.	319616.	321005.	352859.	305930.	243035.	236787.	216615.	2680.	6700.
1980	205130.	197177.	272906.	318565.	246367.	237997.	244006.	313289.	830836.	428648.	250929.	170618.	2710.	16970.
1981	276535.	302281.	324099.	338797.	319081.	285778.	297342.	403458.	1177765.	383028.	258228.	199339.	2660.	29660.
1982	181686.	235755.	305335.	353474.	322334.	380826.	396079.	521712.	783292.	693084.	366962.	276535.	2800.	20000.
1383	328304.	322988.	334671.	341950.	328760.	382830.	394155.	401276.	486347.	635365.	363689.	273263.	3700.	13140.
1984	344271.	457408.	398995.	385983.	359920.	386836.	387035.	587901.	978009.	677990.	482102.	574036.	3620.	21070.
AVE.	281778.	300190.	325470.	316555.	284043.	319183.	339663.	420766.	565450.	420720.	283529.	254320.	1915.	14854.

PROGRAM RES071

RESERVOIR RECORDS STORAGE SYSTEM
MONTHLY RESERVOIR OPERATION RECORD

DATE RUNZ JAN 22, 1985
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CF - CANTON FERRY RESERVOIR   CF40 - TOTAL RESERVOIR DISCHARGE   UNITS AF

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL TOTAL (AF)
1955	198345.	258791.	293728.	261104.	245514.	240143.	164503.	120444.	94226.	212969.	212922.	226183.	2493063.
1956	279967.	275789.	295526.	297500.	295489.	267849.	374301.	529944.	548013.	249957.	258535.	244742.	3918860.
1957	260865.	245159.	259276.	304403.	291530.	290618.	226830.	191226.	655656.	322611.	250943.	244327.	3556560.
1958	262433.	243173.	272926.	334949.	293592.	215792.	364225.	381739.	256383.	320291.	257438.	270188.	3494219.
1959	275773.	237573.	234030.	231946.	189826.	166264.	134797.	399828.	629157.	322155.	166611.	114407.	3102375.
1960	355335.	548985.	699750.	131306.	165243.	274849.	437157.	486357.	398315.	222525.	209602.	238591.	4227985.
1961	255249.	246243.	218955.	273362.	193130.	179683.	229258.	172483.	143523.	217487.	260449.	195911.	2594838.
1962	179051.	254717.	273939.	253504.	208879.	320132.	194066.	129977.	461990.	244542.	265071.	230083.	3035660.
1963	247283.	230353.	239135.	238776.	259415.	242142.	214274.	482717.	884628.	333501.	227841.	243094.	3904169.
1964	268185.	272231.	290976.	234883.	200112.	231907.	250215.	431782.	969540.	490377.	245395.	234129.	4109632.
1965	241469.	291114.	314916.	313329.	292740.	357815.	490016.	673586.	711510.	634115.	247061.	344889.	4924659.
1966	614975.	474744.	355735.	313527.	245851.	307934.	311563.	222565.	189897.	201977.	218935.	166155.	3523858.
1967	165532.	157940.	313557.	362796.	330803.	341078.	223319.	240912.	585461.	552773.	311563.	237719.	3934463.
1968	234565.	202910.	311544.	329720.	318664.	552139.	393580.	399927.	489778.	407821.	291491.	258763.	4189902.
1969	366505.	339987.	329304.	340561.	319039.	450297.	486535.	666019.	556234.	568532.	289160.	247378.	4957811.
1970	225590.	294525.	327154.	339390.	277725.	329554.	447772.	583934.	764945.	509296.	362400.	267273.	4728438.
1971	275616.	316046.	338995.	362755.	335821.	394535.	525399.	777917.	489937.	556939.	308211.	286294.	4979565.
1972	323046.	322076.	335821.	344459.	330744.	335494.	504611.	605950.	552297.	391497.	320528.	337805.	4704430.
1973	353236.	336436.	331373.	308390.	262551.	225342.	179246.	238770.	292998.	297223.	219848.	167543.	3213221.
1974	248509.	299770.	326497.	340066.	317950.	369529.	378248.	451477.	693243.	450466.	315630.	269086.	4457671.
1975	267948.	211795.	310354.	355754.	305911.	367894.	352522.	392215.	690585.	979457.	398737.	320370.	4943642.
1976	359701.	459015.	431544.	368925.	345124.	470301.	645838.	831649.	716132.	442512.	361666.	334254.	5766861.
1977	315729.	324020.	331458.	331497.	266043.	250988.	251980.	212092.	154592.	172403.	206658.	152330.	2969790.
1978	220879.	269772.	339749.	351411.	356747.	400344.	381005.	429054.	481466.	459031.	339332.	294466.	4333258.
1979	257352.	316959.	344330.	365177.	297029.	319516.	321005.	352959.	305930.	243035.	236787.	216615.	3576593.
1980	205130.	197177.	272906.	319565.	246367.	237997.	244006.	313299.	830836.	428648.	250929.	170518.	3716469.
1981	276535.	302291.	324099.	339777.	319081.	285778.	297342.	403458.	1177765.	383028.	258228.	195339.	4565731.
1982	181685.	235755.	305335.	353474.	322334.	390826.	396079.	521712.	783292.	693084.	366962.	275535.	4817074.
1983	329304.	322788.	334571.	341950.	328760.	392830.	394155.	401276.	485347.	635365.	363689.	273263.	4593598.
1984	344271.	457408.	398995.	385983.	359920.	386836.	387035.	597901.	978009.	677990.	482102.	574035.	6020486.
AVG.	291778.	300190.	325470.	316555.	294043.	319183.	339563.	420766.	565450.	420720.	283529.	254320.	4111665.

RESERVOIR RECORDS STORAGE SYSTEM
MONTHLY RESERVOIR OPERATION RECORD

CF - CANYON FERRY RESERVOIR   CF42 - POWER TURBINE DISCHARGE   UNITS% AF

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	DAILY MINIMUM (CFS)	DAILY MAXIMUM (CFS)
1955	188323.	257831.	283928.	261104.	245514.	240143.	164503.	120444.	84226.	124233.	208401.	226183.	260.	5785.
1956	279967.	275788.	295626.	297600.	296489.	267848.	148859.	141104.	137454.	162506.	258585.	244742.	0.	5710.
1957	260866.	246168.	269276.	304403.	291630.	290618.	226830.	189838.	88007.	196502.	250949.	246327.	0.	5750.
1958	262433.	243173.	292026.	334849.	293692.	215782.	134777.	16582.	97686.	174625.	259438.	270188.	0.	5680.
1959	276773.	237679.	234030.	231848.	188826.	161494.	132278.	35425.	43696.	79398.	153997.	106373.	0.	5160.
1960	55021.	53772.	58076.	100820.	147332.	182717.	106116.	122916.	112879.	191544.	192337.	230400.	340.	4760.
1961	256522.	240139.	218955.	273362.	193130.	179683.	219868.	148264.	111848.	181170.	228793.	164826.	0.	5740.
1962	186843.	245573.	271616.	263504.	208879.	320132.	181269.	111471.	29653.	112324.	247259.	218479.	0.	6160.
1963	234109.	234764.	238135.	238776.	197573.	242142.	211656.	47246.	37388.	143802.	201699.	230638.	160.	5190.
1964	261084.	258049.	285461.	234883.	200112.	231907.	221732.	48972.	73864.	98995.	203821.	227861.	0.	5300.
1965	236489.	291114.	314916.	313329.	292740.	324595.	215821.	58612.	106671.	200291.	176430.	222486.	0.	5680.
1966	269752.	284925.	307398.	313527.	245851.	307934.	302479.	193487.	149474.	159154.	176509.	144000.	560.	5890.
1967	160324.	167940.	313567.	362796.	330803.	334611.	217487.	227702.	274790.	318287.	274592.	217527.	2390.	6170.
1968	231749.	202810.	311544.	328720.	318664.	296806.	328225.	371068.	340701.	322730.	256978.	212529.	0.	6250.
1969	311068.	279987.	328304.	340661.	318099.	362727.	358810.	339292.	307547.	315778.	255620.	227782.	3390.	6215.
1970	219074.	294525.	327154.	338380.	277725.	329554.	357520.	375074.	320836.	317782.	327114.	244165.	2810.	6240.
1971	295418.	315808.	338896.	362955.	335821.	384535.	361011.	368965.	340601.	318030.	270506.	272053.	3540.	6390.
1972	322671.	322076.	335821.	344469.	330744.	335484.	343674.	369679.	320866.	320251.	292621.	319200.	3580.	6110.
1973	351292.	336496.	331378.	308390.	262651.	225342.	161514.	202512.	252456.	255411.	179445.	147868.	0.	6030.
1974	248192.	298770.	326697.	340066.	317950.	368529.	363967.	361894.	315897.	315134.	287425.	256225.	2860.	6210.
1975	264853.	211795.	310354.	355954.	305911.	367894.	352522.	368192.	325904.	319795.	323147.	313884.	3460.	6170.
1976	325805.	311405.	331438.	338697.	309759.	366129.	372456.	376165.	317911.	319458.	331735.	326102.	3790.	6390.
1977	315729.	313844.	323048.	331497.	266043.	250988.	241924.	172641.	119286.	138050.	177640.	145269.	1960.	5610.
1978	220879.	269772.	329811.	351411.	338896.	378109.	351630.	368687.	322036.	318962.	302320.	283676.	2360.	6280.
1979	267114.	316859.	344330.	365177.	287028.	319616.	317097.	314003.	264178.	199993.	200549.	196760.	2080.	6190.
1980	204873.	197177.	272906.	318565.	246367.	237997.	233712.	265329.	301527.	321937.	210922.	152787.	2490.	5370.
1981	276377.	302281.	324099.	338797.	319081.	285778.	278142.	261025.	311544.	317097.	219154.	173117.	2580.	5950.
1982	181468.	235755.	305335.	353474.	322334.	380826.	367319.	380053.	336416.	323385.	330744.	257395.	2800.	6300.
1983	328304.	322988.	334671.	341950.	317058.	361884.	363471.	373725.	323147.	325587.	332985.	259438.	3660.	6160.
1984	299901.	325349.	341097.	355239.	344628.	386836.	373725.	378307.	331081.	332271.	315411.	346195.	3590.	6430.
AVE.	253109.	263154.	296663.	311507.	278378.	297955.	267013.	236956.	216652.	240816.	248238.	229483.	1622.	5909.

RESERVOIR RECORDS STORAGE SYSTEM
MONTHLY RESERVOIR OPERATION RECORD

CF - CANYON FERRY RESERVOIR　　CF42 - POWER TURBINE DISCHARGE　　UNITS AF

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL TOTAL (AF)
1955	189323.	257831.	283928.	261104.	245514.	240143.	164503.	120444.	84226.	124233.	208401.	226183.	2404833.
1956	273967.	275788.	295625.	297500.	296483.	267848.	148859.	141104.	137454.	152506.	258585.	244742.	2806569.
1957	260856.	246168.	259275.	304403.	291630.	290518.	226830.	189938.	88007.	195502.	230945.	246327.	2861414.
1958	262433.	243173.	292026.	334847.	293692.	215752.	134777.	16582.	97686.	174625.	259438.	270188.	2595251.
1959	275773.	237679.	234030.	221946.	188826.	151494.	132278.	35425.	43696.	79398.	153997.	106373.	1881817.
1960	53021.	53772.	59075.	100920.	147332.	182717.	106116.	122916.	112879.	191544.	192337.	230400.	1553930.
1961	256522.	240133.	218955.	273362.	193130.	179583.	219858.	148264.	111848.	191170.	228793.	164826.	2415560.
1962	195943.	245573.	271616.	263304.	208879.	320132.	191259.	111471.	29653.	112324.	247257.	218479.	2397602.
1963	234109.	234764.	239135.	238776.	197573.	242142.	211656.	47246.	37388.	143802.	201599.	230536.	2257929.
1964	251094.	259049.	255461.	234993.	200112.	231907.	221732.	48972.	73864.	98995.	203821.	227851.	2346741.
1965	236487.	291114.	314916.	313329.	292740.	324595.	215821.	56512.	106671.	290291.	176430.	222496.	2753494.
1966	259752.	254925.	307398.	313527.	245551.	307934.	302479.	193497.	149474.	159154.	176509.	144000.	2954490.
1967	150324.	157940.	313567.	352796.	330803.	334511.	217487.	227702.	274790.	319297.	274592.	217527.	3200426.
1968	231749.	202910.	311544.	328720.	318554.	295806.	329225.	371058.	340701.	322730.	256978.	212529.	3522524.
1969	311066.	279987.	328304.	340551.	318099.	362727.	358810.	339292.	307547.	315778.	255620.	227792.	3745675.
1970	219074.	294525.	327154.	338390.	277725.	329554.	357520.	375074.	320836.	317782.	327114.	244165.	3728903.
1971	295416.	315805.	339896.	362955.	335821.	384535.	351011.	358965.	340601.	318030.	270506.	272053.	3964599.
1972	322671.	322076.	335821.	344469.	330744.	335484.	343574.	359579.	320866.	320251.	292621.	319200.	3757556.
1973	331292.	336496.	331379.	308390.	262651.	225342.	151514.	202512.	252456.	255411.	179445.	147969.	3014755.
1974	249132.	298770.	326697.	340056.	317950.	368529.	353967.	351994.	315997.	315134.	297425.	256225.	3800746.
1975	264953.	211795.	310354.	355954.	305911.	367894.	352522.	358192.	325904.	319795.	323147.	313984.	3920205.
1976	325905.	311405.	331436.	338697.	309759.	366129.	372456.	376165.	317911.	319458.	331735.	326102.	4027060.
1977	315729.	313844.	323048.	331497.	256043.	250988.	241924.	172541.	119286.	138050.	177640.	145269.	2795959.
1978	220979.	259772.	329811.	351411.	338876.	378109.	351530.	368597.	322036.	318962.	302320.	293675.	3836189.
1979	267114.	316859.	344330.	355177.	287028.	319516.	317097.	314003.	254178.	199993.	200549.	196760.	3392704.
1980	204973.	197177.	272905.	218555.	246367.	237997.	233712.	265329.	301527.	321937.	210922.	152797.	2954099.
1981	275377.	302291.	324099.	338797.	319081.	285779.	278142.	251025.	311544.	317097.	215154.	172117.	3406492.
1982	191469.	235755.	305335.	353474.	322334.	380826.	367319.	390053.	336416.	323385.	330744.	237395.	3774504.
1983	329304.	322998.	334571.	341950.	317058.	351894.	363471.	373725.	323147.	325587.	332985.	259438.	3985208.
1984	299701.	325349.	341097.	355239.	344628.	386836.	373725.	378307.	331081.	332271.	315411.	346195.	4130040.
AVE.	253109.	263154.	296563.	311507.	278378.	297955.	267013.	236936.	216552.	240816.	248238.	225483.	3139922.

PROGRAM RESO70

RESERVOIR RECORDS STORAGE SYSTEM
MONTHLY RESERVOIR OPERATION RECORD

DATE RUN% DEC 18, 1984
PAGE 055

CF - CANYON FERRY RESERVOIR   CF44 - PUMP TURBINE DISCHARGE   UNITS% AF

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	DAILY MINIMUM (CFS)	DAILY MAXIMUM (CFS)
1955	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1956	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1957	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1958	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1959	0.	0.	0.	0.	0.	2856.	20.	4661.	7874.	11107.	6347.	4314.	0.	240.
1960	4026.	1309.	0.	0.	0.	238.	3907.	6803.	12972.	15590.	8767.	5157.	0.	280.
1961	5593.	4324.	0.	0.	0.	0.	4780.	14202.	17653.	19934.	18764.	12813.	0.	380.
1962	7537.	5494.	1309.	0.	0.	0.	1726.	10195.	8926.	15352.	8767.	5831.	0.	290.
1963	7775.	0.	0.	0.	0.	0.	1309.	11663.	8886.	14420.	13527.	6466.	0.	320.
1964	3749.	7279.	2678.	0.	0.	0.	7914.	7974.	11623.	16602.	16661.	3293.	0.	340.
1965	2618.	0.	0.	0.	0.	0.	7041.	8172.	18010.	11881.	13488.	3451.	0.	360.
1966	0.	0.	0.	0.	0.	0.	4919.	16046.	21997.	23127.	23127.	12595.	0.	400.
1967	3491.	0.	0.	0.	0.	3907.	3531.	7775.	14023.	17554.	18922.	10869.	0.	330.
1968	1666.	0.	0.	0.	0.	0.	5246.	16740.	13418.	17693.	17494.	6228.	0.	350.
1969	3412.	0.	0.	0.	0.	0.	3352.	15709.	19795.	12526.	17137.	9798.	0.	340.
1970	3253.	0.	0.	0.	0.	0.	6962.	15253.	20013.	19339.	17990.	11960.	0.	360.
1971	99.	0.	0.	0.	0.	0.	7634.	18486.	19577.	20271.	18962.	7418.	0.	420.
1972	79.	0.	0.	0.	0.	0.	6446.	17950.	20747.	20112.	14241.	9838.	0.	390.
1973	1071.	0.	0.	0.	0.	0.	10294.	19379.	20747.	20906.	20569.	10393.	0.	390.
1974	159.	0.	0.	0.	0.	0.	7755.	17455.	19180.	20906.	14479.	6288.	0.	360.
1975	1607.	0.	0.	0.	0.	0.	0.	8152.	16205.	15134.	14043.	4106.	0.	400.
1976	79.	0.	0.	0.	0.	0.	7894.	16602.	17653.	19279.	15174.	4879.	0.	380.
1977	0.	0.	0.	0.	0.	0.	5355.	20588.	17494.	17415.	14678.	3709.	0.	380.
1978	0.	0.	5098.	0.	0.	0.	6744.	18188.	20926.	13031.	18664.	5653.	0.	370.
1979	139.	0.	0.	0.	0.	0.	2241.	21223.	21421.	21521.	18486.	10830.	0.	380.
1980	139.	0.	0.	0.	0.	0.	5831.	22056.	11544.	13230.	20648.	9481.	0.	370.
1981	79.	0.	0.	0.	0.	0.	10850.	8767.	10889.	19021.	19974.	14539.	0.	350.
1982	119.	0.	0.	0.	0.	0.	3312.	18486.	18942.	16324.	18307.	10235.	0.	360.
1983	0.	0.	0.	0.	0.	0.	10750.	15431.	18486.	13944.	15610.	7299.	0.	360.
1984	0.	0.	0.	0.	0.	0.	7121.	18228.	18466.	19259.	18843.	14182.	0.	330.
AVE.	1556.	614.	303.	0.	0.	233.	4764.	12539.	14249.	14849.	14122.	7054.	0.	308.

PROGRAM RES071

RESERVOIR RECORDS STORAGE SYSTEM
MONTHLY RESERVOIR OPERATION RECORD

DATE RUN: JAN 22, 1985
PAGE 009

CF - CANYON FERRY RESERVOIR

CF44 - PUMP TURBINE DISCHARGE

UNITS AF

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL TOTAL (AF)
1955	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1956	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1957	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1958	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1959	0.	0.	0.	0.	0.	2856.	20.	4561.	7874.	11107.	6347.	4314.	37179.
1960	4026.	1309.	0.	0.	0.	238.	3907.	6803.	12972.	15590.	8767.	5157.	55769.
1961	5593.	4324.	0.	0.	0.	0.	4730.	14202.	17653.	19934.	18764.	12813.	98053.
1962	7527.	5494.	1309.	0.	0.	0.	1726.	10195.	8926.	15352.	8757.	5831.	65137.
1963	7775.	0.	0.	0.	0.	0.	1309.	11663.	8886.	14420.	13527.	6466.	64046.
1964	3749.	7279.	2678.	0.	0.	0.	7914.	7974.	11623.	15602.	16661.	3293.	77773.
1965	2519.	0.	0.	0.	0.	0.	7041.	8172.	19010.	11891.	13498.	3451.	64661.
1966	0.	0.	0.	0.	0.	0.	4919.	16046.	21997.	23127.	23127.	12595.	101811.
1967	3491.	0.	0.	0.	0.	3907.	3531.	7775.	14023.	17554.	13922.	10869.	80072.
1968	1666.	0.	0.	0.	0.	0.	5246.	16740.	13418.	17693.	17494.	6229.	79485.
1969	3412.	0.	0.	0.	0.	0.	3352.	15799.	19795.	12526.	17137.	9798.	81729.
1970	3253.	0.	0.	0.	0.	0.	6952.	15253.	20013.	19339.	17999.	11960.	94770.
1971	99.	0.	0.	0.	0.	0.	7634.	18486.	19577.	20271.	18962.	7418.	92447.
1972	79.	0.	0.	0.	0.	0.	6445.	17950.	20747.	20112.	14241.	5838.	83413.
1973	1071.	0.	0.	0.	0.	0.	10294.	19379.	20747.	20306.	20569.	10393.	103359.
1974	159.	0.	0.	0.	0.	0.	7755.	17455.	19180.	20906.	14479.	6288.	85222.
1975	1607.	0.	0.	0.	0.	0.	0.	8152.	16205.	15134.	14043.	4106.	59247.
1976	79.	0.	0.	0.	0.	0.	7894.	15502.	17553.	19279.	15174.	4879.	81560.
1977	0.	0.	0.	0.	0.	0.	5355.	20588.	17494.	17415.	14673.	3709.	79239.
1978	0.	0.	5078.	0.	0.	0.	6744.	18188.	20926.	13031.	18654.	5553.	85304.
1979	139.	0.	0.	0.	0.	0.	2241.	21223.	21421.	21521.	18486.	10830.	95861.
1980	139.	0.	0.	0.	0.	0.	5831.	22056.	11544.	13230.	20648.	9481.	82929.
1981	79.	0.	0.	0.	0.	0.	10850.	8757.	10889.	19021.	19974.	14539.	84119.
1982	119.	0.	0.	0.	0.	0.	3312.	18486.	18942.	16324.	18307.	10235.	85725.
1983	0.	0.	0.	0.	0.	0.	10750.	15431.	18486.	13944.	15610.	7299.	81520.
1984	0.	0.	0.	0.	0.	0.	7121.	18228.	18466.	19259.	18843.	14182.	96099.
AVE.	1556.	614.	303.	0.	0.	233.	4764.	12539.	14249.	14849.	14122.	7054.	70285.

PROGRAM RES070

RESERVOIR RECORDS STORAGE SYSTEM
MONTHLY RESERVOIR OPERATION RECORD

DATE RUN% DEC 18, 1984
PAGE 056

CF - CANYON FERRY RESERVOIR

CF46 - PUMPED TO HELENA VALLEY

UNITS% AF

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	DAILY MINIMUM (CFS)	DAILY MAXIMUM (CFS)
1955	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1956	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1957	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1958	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1959	0.	0.	0.	0.	0.	1914.	20.	3927.	7121.	10949.	6268.	3719.	0.	250.
1960	3451.	1111.	0.	0.	0.	198.	3134.	6188.	12337.	15392.	7498.	3134.	0.	280.
1961	3134.	1785.	0.	0.	0.	0.	3610.	10017.	14122.	16383.	12893.	8271.	0.	320.
1962	4681.	3650.	912.	0.	0.	0.	1071.	8311.	8529.	15927.	9045.	5772.	0.	310.
1963	7398.	0.	0.	0.	0.	0.	1309.	12179.	9759.	14975.	12615.	5990.	0.	340.
1964	3352.	6902.	2737.	0.	0.	0.	7359.	6545.	11603.	17038.	17256.	2975.	0.	340.
1965	2360.	0.	0.	0.	0.	0.	5831.	6565.	16304.	12159.	13845.	3987.	0.	340.
1966	0.	0.	0.	0.	0.	0.	4165.	13031.	18426.	19696.	19299.	9560.	0.	350.
1967	2717.	0.	0.	0.	0.	2559.	2301.	5435.	10850.	18010.	18050.	9322.	0.	310.
1968	1150.	0.	0.	0.	0.	0.	4017.	12119.	11177.	18288.	17018.	5712.	0.	330.
1969	3193.	0.	0.	0.	0.	0.	2757.	14132.	19597.	12684.	16403.	9798.	0.	340.
1970	3253.	0.	0.	0.	0.	0.	6010.	11464.	19081.	19874.	17296.	11147.	0.	340.
1971	99.	0.	0.	0.	0.	0.	5871.	13567.	16423.	20628.	18744.	6823.	0.	340.
1972	60.	0.	0.	0.	0.	0.	5988.	14380.	19041.	20727.	13765.	8767.	0.	340.
1973	873.	0.	0.	0.	0.	0.	7438.	16879.	19795.	20906.	19835.	9382.	0.	340.
1974	159.	0.	0.	0.	0.	0.	6526.	14658.	18367.	20291.	13726.	5574.	0.	340.
1975	1388.	0.	0.	0.	0.	0.	0.	5871.	14836.	16126.	14420.	2380.	0.	330.
1976	60.	0.	0.	0.	0.	0.	6486.	13448.	15927.	18883.	14757.	3273.	0.	340.
1977	0.	0.	0.	0.	0.	0.	4701.	18863.	17812.	16939.	14340.	3352.	0.	380.
1978	0.	0.	4840.	0.	0.	0.	5574.	15213.	19676.	13031.	18347.	5137.	0.	350.
1979	99.	0.	0.	0.	0.	0.	1666.	17633.	20331.	21521.	17752.	9025.	0.	350.
1980	119.	0.	0.	0.	0.	0.	4463.	19617.	11504.	13111.	19359.	8350.	0.	350.
1981	79.	0.	0.	0.	0.	0.	8350.	7220.	11008.	18942.	19101.	11683.	0.	340.
1982	99.	0.	0.	0.	0.	0.	2638.	14876.	17236.	16245.	17911.	8906.	0.	310.
1983	0.	0.	0.	0.	0.	0.	7855.	12119.	17851.	13150.	15094.	6526.	0.	300.
1984	0.	0.	0.	0.	0.	0.	5732.	15114.	17673.	19259.	18625.	11762.	0.	330.
AVE.	1257.	448.	283.	0.	0.	156.	3829.	10312.	13213.	14704.	13442.	6011.	0.	286.

PROGRAM RES071

RESERVOIR RECORDS STORAGE SYSTEM
MONTHLY RESERVOIR OPERATION RECORD

DATE RUN: JAN 22, 1985
PAGE 010

CF - CANYON FERRY RESERVOIR

CF46 - PUMPED TO HELENA VALLEY

UNITS AF

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL TOTAL (AF)
1955	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1956	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1957	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1958	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1959	0.	0.	0.	0.	0.	1914.	20.	3927.	7121.	10949.	6268.	3719.	33918.
1960	3451.	1111.	0.	0.	0.	198.	3134.	5188.	12337.	15392.	7438.	3134.	52443.
1961	3134.	1795.	0.	0.	0.	0.	3610.	10017.	14122.	15383.	12893.	8271.	70215.
1962	4681.	3550.	912.	0.	0.	0.	1071.	8311.	8529.	15327.	9045.	5772.	57898.
1963	7398.	0.	0.	0.	0.	0.	1309.	12179.	9759.	14975.	12615.	5990.	64225.
1964	3352.	5902.	2737.	0.	0.	0.	7359.	6545.	11503.	17038.	17256.	2375.	75757.
1965	2360.	0.	0.	0.	0.	0.	5931.	6555.	16304.	12159.	13845.	3387.	61051.
1966	0.	0.	0.	0.	0.	0.	4165.	13031.	19426.	19696.	19233.	5560.	84177.
1967	2717.	0.	0.	0.	0.	2559.	2301.	5435.	10850.	18010.	18050.	5322.	69244.
1968	1150.	0.	0.	0.	0.	0.	4017.	12117.	11177.	18288.	17019.	5712.	69481.
1969	3193.	0.	0.	0.	0.	0.	2757.	14132.	19597.	12584.	16403.	5738.	79564.
1970	3253.	0.	0.	0.	0.	0.	6010.	11464.	19081.	13974.	17276.	11147.	89125.
1971	99.	0.	0.	0.	0.	0.	5871.	13567.	16423.	20628.	18744.	6823.	82155.
1972	50.	0.	0.	0.	0.	0.	5938.	14380.	19041.	20727.	13755.	8767.	82728.
1973	973.	0.	0.	0.	0.	0.	7438.	16979.	19795.	20906.	19835.	5392.	95109.
1974	157.	0.	0.	0.	0.	0.	6526.	14658.	18367.	20291.	13726.	5574.	79301.
1975	1388.	0.	0.	0.	0.	0.	0.	5871.	14836.	16125.	14420.	2380.	55021.
1976	60.	0.	0.	0.	0.	0.	6485.	13448.	15927.	18893.	14757.	3273.	72834.
1977	0.	0.	0.	0.	0.	0.	4701.	19853.	17912.	16939.	14340.	3352.	75007.
1978	0.	0.	4840.	0.	0.	0.	5574.	15213.	19576.	13031.	19347.	5137.	81818.
1979	59.	0.	0.	0.	0.	0.	1666.	17633.	20331.	21521.	17752.	5025.	89027.
1980	117.	0.	0.	0.	0.	0.	4453.	19517.	11504.	13111.	19359.	8350.	76523.
1981	79.	0.	0.	0.	0.	0.	8350.	7220.	11008.	18942.	19101.	11593.	76383.
1982	93.	0.	0.	0.	0.	0.	2638.	14876.	17236.	16245.	17911.	8906.	77911.
1983	0.	0.	0.	0.	0.	0.	7855.	12119.	17851.	13150.	15094.	6526.	72595.
1984	0.	0.	0.	0.	0.	0.	5732.	15114.	17673.	19259.	19525.	11762.	89165.
AVE.	1257.	448.	283.	0.	0.	156.	3829.	10312.	13213.	14704.	13442.	6011.	63656.

RESERVOIR RECORDS STORAGE SYSTEM
MONTHLY RESERVOIR OPERATION RECORD

CF - CANYON FERRY RESERVOIR　　CF48 - SPILLWAY AND RIVER OUTLETS　　UNITS% AF

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	DAILY MINIMUM (CFS)	DAILY MAXIMUM (CFS)
1955	24.	950.	0.	0.	0.	0.	0.	0.	0.	88736.	4520.	0.	0.	5635.
1956	0.	0.	0.	0.	0.	0.	225441.	388839.	410558.	87451.	0.	0.	0.	21140.
1957	0.	0.	0.	0.	0.	0.	0.	1388.	567649.	126109.	0.	0.	0.	14980.
1958	0.	0.	0.	0.	0.	0.	229448.	365157.	158697.	145666.	0.	0.	0.	7000.
1959	0.	0.	0.	0.	0.	0.	2479.	355815.	570466.	220701.	0.	0.	0.	17970.
1960	302896.	492793.	631874.	90486.	17911.	91696.	324000.	350459.	260727.	0.	0.	0.	0.	15010.
1961	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1962	0.	0.	0.	0.	0.	0.	0.	0.	414882.	100939.	0.	0.	0.	12600.
1963	0.	45600.	0.	0.	71841.	0.	0.	411630.	828595.	160304.	0.	0.	0.	14330.
1964	0.	0.	0.	0.	0.	0.	13210.	368291.	872449.	347742.	7656.	0.	0.	23740.
1965	0.	0.	0.	0.	0.	43220.	261322.	600238.	570624.	409785.	43299.	116965.	0.	16010.
1966	345223.	189818.	48337.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	6060.
1967	0.	0.	0.	0.	0.	0.	0.	0.	285798.	198922.	0.	0.	0.	11570.
1968	0.	0.	0.	0.	0.	255332.	56093.	0.	124483.	49111.	0.	34294.	0.	6370.
1969	48932.	60000.	0.	0.	0.	87570.	121616.	296886.	209296.	227544.	0.	0.	0.	9190.
1970	0.	0.	0.	0.	0.	0.	77280.	182043.	405015.	152301.	0.	0.	0.	9320.
1971	0.	238.	0.	0.	0.	0.	150883.	376899.	113335.	198010.	0.	0.	0.	9170.
1972	238.	0.	0.	0.	0.	0.	148502.	203940.	191643.	30407.	0.	0.	0.	6220.
1973	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1974	0.	0.	0.	0.	0.	0.	0.	57471.	339798.	94135.	0.	0.	0.	11280.
1975	0.	0.	0.	0.	0.	0.	0.	0.	333639.	628403.	47127.	0.	0.	16800.
1976	33957.	147610.	100106.	30228.	35365.	104172.	259002.	425434.	364641.	84893.	0.	0.	0.	9590.
1977	0.	10175.	8410.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	880.
1978	0.	0.	0.	0.	17851.	22235.	17058.	26975.	118830.	124007.	0.	0.	0.	4000.
1979	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1980	0.	0.	0.	0.	0.	0.	0.	6288.	506261.	80370.	0.	0.	0.	11390.
1981	0.	0.	0.	0.	0.	0.	0.	126446.	844324.	27967.	0.	0.	0.	20060.
1982	0.	0.	0.	0.	0.	0.	22810.	108297.	410697.	337130.	0.	0.	0.	14200.
1983	0.	0.	0.	0.	11702.	20945.	12079.	0.	126863.	282684.	0.	0.	0.	7580.
1984	44370.	132059.	57897.	30744.	15293.	0.	456.	176251.	610790.	307200.	129223.	201897.	0.	15020.
AVE.	25855.	35975.	28221.	5049.	5665.	20839.	64056.	160958.	321335.	150351.	7728.	11772.	0.	10571.

RESERVOIR RECORDS STORAGE SYSTEM
MONTHLY RESERVOIR OPERATION RECORD

CF - CANYON FERRY RESERVOIR CF-8 - SPILLWAY AND RIVER OUTLETS UNITS AF

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL TOTAL (AF)
1955	24.	350.	0.	0.	0.	0.	0.	0.	0.	88735.	4520.	0.	94230.
1956	0.	0.	0.	0.	0.	0.	225441.	398939.	410558.	97451.	0.	0.	1112289.
1957	0.	0.	0.	0.	0.	0.	0.	1399.	567649.	126109.	0.	0.	695146.
1958	0.	0.	0.	0.	0.	0.	229448.	365157.	158697.	145666.	0.	0.	899968.
1959	0.	0.	0.	0.	0.	0.	2479.	355815.	570466.	220701.	0.	0.	1149461.
1960	302896.	432733.	631374.	90486.	17911.	71696.	324000.	350459.	260727.	0.	0.	0.	2562942.
1961	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1962	0.	0.	0.	0.	0.	0.	0.	0.	414882.	100939.	0.	0.	515821.
1963	0.	45600.	0.	0.	71941.	0.	0.	411530.	828595.	160304.	0.	0.	1517970.
1964	0.	0.	0.	0.	0.	0.	13210.	358291.	872449.	347742.	7556.	0.	1603348.
1965	0.	0.	0.	0.	0.	43220.	261322.	600238.	570624.	409795.	43299.	116765.	2045453.
1966	345223.	189815.	48337.	0.	0.	0.	0.	0.	0.	0.	0.	0.	583378.
1967	0.	0.	0.	0.	0.	0.	0.	0.	285798.	198922.	0.	0.	484720.
1968	0.	0.	0.	0.	0.	255332.	56093.	0.	124483.	49111.	0.	34294.	519313.
1969	48932.	60000.	0.	0.	0.	87570.	121616.	276886.	209296.	227544.	0.	0.	1051844.
1970	0.	0.	0.	0.	0.	0.	77280.	132043.	405015.	152301.	0.	0.	815639.
1971	0.	238.	0.	0.	0.	0.	150893.	376939.	113335.	198010.	0.	0.	839355.
1972	238.	0.	0.	0.	0.	0.	148502.	203940.	191643.	30407.	0.	0.	574730.
1973	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1974	0.	0.	0.	0.	0.	0.	0.	57471.	339798.	94135.	0.	0.	491404.
1975	0.	0.	0.	0.	0.	0.	0.	0.	333639.	628403.	47127.	0.	1009169.
1976	33957.	147610.	190105.	30228.	35355.	104172.	259002.	425434.	364641.	94893.	0.	0.	1595408.
1977	0.	10175.	8410.	0.	0.	0.	0.	0.	0.	0.	0.	0.	19585.
1978	0.	0.	0.	0.	17851.	22235.	17058.	26975.	118830.	124007.	0.	0.	326956.
1979	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1980	0.	0.	0.	0.	0.	0.	0.	6288.	506261.	80370.	0.	0.	592919.
1981	0.	0.	0.	0.	0.	0.	0.	126445.	844324.	27967.	0.	0.	998737.
1982	0.	0.	0.	0.	0.	0.	22810.	109297.	410697.	337130.	0.	0.	879934.
1983	0.	0.	0.	0.	11702.	20945.	12079.	0.	125863.	282684.	0.	0.	454273.
1984	44370.	132053.	57897.	30744.	15293.	0.	456.	176251.	610790.	307200.	129223.	201997.	1706180.
AVE.	25955.	35975.	28221.	5049.	5455.	20839.	64956.	150758.	321335.	150351.	7728.	11772.	837803.

PROGRAM RESO70

RESERVOIR RECORDS STORAGE SYSTEM
MONTHLY RESERVOIR OPERATION RECORD

DATE RUN% DEC 18, 1984
PAGE 058

CF - CANYON FERRY RESERVOIR   CF50 - CANYON FERRY - GENERATION% MILLION KILOWATT-HOURS   UNITS% AF

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	DAILY MINIMUM (AF)	DAILY MAXIMUM (AF)
1955	19.38	28.18	30.87	29.47	26.88	25.56	17.34	12.92	9.22	12.94	28.20	30.02	0.00	0.00
1956	36.40	35.38	37.44	37.37	35.78	31.28	17.71	17.39	18.32	21.89	34.07	31.49	0.00	0.00
1957	33.11	31.48	34.26	37.74	35.03	33.57	26.14	22.62	11.83	25.27	32.81	31.62	0.00	0.00
1958	33.21	31.13	37.60	41.62	35.25	26.42	16.96	2.00	12.71	23.15	33.80	34.45	0.00	0.00
1959	34.82	29.91	29.74	29.16	23.48	20.39	17.00	4.38	5.73	10.57	20.51	13.93	0.00	0.00
1960	7.27	7.06	7.30	12.77	19.54	24.73	13.98	16.40	14.99	25.13	24.57	28.88	0.00	0.00
1961	31.08	28.70	26.00	32.17	22.28	21.17	26.15	16.73	13.48	21.70	25.69	17.87	0.00	0.00
1962	20.60	28.20	30.66	29.31	23.95	34.54	19.75	13.24	3.73	14.91	33.22	29.05	0.00	0.00
1963	31.18	32.32	32.11	32.34	26.42	32.90	28.58	6.10	4.89	18.96	26.26	29.67	0.00	0.00
1964	33.54	33.34	36.55	29.68	25.33	29.37	28.14	6.16	9.75	13.35	27.09	30.22	0.00	0.00
1965	31.26	39.01	41.62	40.79	37.60	40.58	26.81	7.00	13.63	26.85	23.65	30.31	0.00	0.00
1966	33.45	36.34	38.42	37.74	29.03	35.92	35.96	23.21	17.94	19.10	20.06	16.01	0.00	0.00
1967	17.88	19.44	36.52	39.90	34.68	33.68	21.76	23.32	35.04	42.36	35.21	27.14	0.00	0.00
1968	28.88	26.98	41.00	41.47	39.40	41.81	39.63	40.84	41.54	42.88	33.06	27.68	0.00	0.00
1969	40.63	36.42	42.39	42.40	38.18	42.12	40.82	42.35	41.02	42.21	34.26	30.73	0.00	0.00
1970	30.01	40.25	42.41	42.41	34.70	40.06	40.64	41.59	40.98	42.31	42.39	30.70	0.00	0.00
1971	37.81	40.77	42.94	43.49	39.31	43.21	39.88	40.50	40.95	42.35	35.26	35.25	0.00	0.00
1972	41.80	41.73	43.09	42.76	39.67	40.16	40.97	42.41	41.11	42.51	37.32	39.15	0.00	0.00
1973	42.33	40.98	39.65	36.32	30.94	26.17	19.17	24.99	32.81	33.54	22.92	18.56	0.00	0.00
1974	32.22	38.99	42.32	42.35	38.33	42.49	41.00	42.40	40.93	42.00	36.68	32.93	0.00	0.00
1975	33.34	26.79	39.20	42.56	35.11	40.96	38.09	40.80	41.53	43.18	43.24	41.73	0.00	0.00
1976	43.29	41.58	43.25	43.32	38.54	43.47	41.93	43.10	41.50	42.64	43.30	41.72	0.00	0.00
1977	41.28	41.76	42.95	42.88	33.49	31.25	30.07	21.80	15.22	17.81	22.62	18.28	0.00	0.00
1978	28.64	35.14	42.55	43.11	39.05	42.20	39.56	43.13	41.54	42.62	39.17	35.40	0.00	0.00
1979	34.35	40.39	42.77	42.44	32.19	36.10	35.84	38.48	33.83	26.34	25.66	24.86	0.00	0.00
1980	25.53	24.84	34.42	38.54	28.69	27.84	27.88	33.95	40.60	42.91	26.98	19.32	0.00	0.00
1981	36.26	39.60	42.16	43.05	38.72	34.25	32.63	32.95	41.98	42.08	28.07	21.61	0.00	0.00
1982	22.91	30.25	39.45	42.94	37.66	42.75	40.84	42.73	41.95	43.37	43.32	32.82	0.00	0.00
1983	42.48	41.98	43.44	43.52	39.31	43.52	42.06	43.47	42.12	43.64	43.66	33.42	0.00	0.00
1984	39.65	43.01	44.25	44.46	41.67	44.64	42.54	44.52	43.22	44.39	41.43	42.52	0.00	0.00
AVE.	32.15	33.73	37.58	38.27	33.34	35.10	30.99	27.72	27.80	31.77	32.15	29.24	0.00	0.00

RESERVOIR RECORDS STORAGE SYSTEM
MONTHLY RESERVOIR OPERATION RECORD

CF - CANYON FERRY RESERVOIR   CFSO - CANYON FERRY - GENERATION: MILLION KILOWATT-HOURS   UNITS AF

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL TOTAL (AF)
1955	19.33	28.18	30.87	29.47	26.99	25.56	17.34	12.92	9.22	12.94	28.20	30.02	270.98
1956	35.40	35.38	37.44	37.37	35.78	31.28	17.71	17.39	18.32	21.89	34.07	31.49	354.52
1957	33.11	31.49	34.26	37.74	35.03	33.57	26.14	22.62	11.83	25.27	32.81	31.52	355.48
1958	33.21	31.13	37.50	41.62	35.25	26.42	16.95	2.00	12.71	23.15	33.80	34.45	328.30
1959	34.92	27.91	25.74	29.15	23.48	20.39	17.00	4.38	5.73	10.57	20.51	13.93	239.62
1960	7.27	7.05	7.30	12.77	19.54	24.73	13.98	16.40	14.99	25.13	24.57	23.98	202.62
1961	31.08	25.70	25.00	32.17	22.28	21.17	26.15	16.73	13.49	21.70	25.69	17.97	293.02
1962	20.60	29.20	30.66	29.31	23.95	34.54	19.75	13.24	3.73	14.91	33.22	29.05	291.16
1963	31.18	32.32	32.11	32.34	25.42	32.90	26.58	6.10	4.89	19.96	26.25	29.67	301.73
1964	33.54	33.34	36.55	29.68	25.33	29.37	28.14	5.16	9.75	13.35	27.09	30.22	302.52
1965	31.26	37.01	41.52	40.79	37.60	40.58	26.91	7.00	13.63	25.95	23.55	30.31	359.11
1966	33.45	35.34	36.42	37.74	29.03	35.92	35.95	23.21	17.94	19.10	20.06	16.01	343.19
1967	17.89	17.44	36.52	39.90	34.69	33.68	21.76	23.32	35.04	42.36	35.21	27.14	356.93
1968	29.89	26.98	41.00	41.47	39.49	41.81	39.53	40.84	41.54	42.88	33.06	27.68	445.17
1969	40.53	35.42	42.39	42.40	39.18	42.12	40.82	42.35	41.02	42.21	34.25	30.73	473.53
1970	30.01	40.25	42.41	42.41	34.70	40.06	40.64	41.59	40.93	42.31	42.39	30.70	468.45
1971	37.81	40.77	42.94	43.49	39.31	43.21	39.88	40.50	40.95	42.35	35.28	35.25	491.72
1972	41.90	41.73	43.07	42.76	39.57	40.16	40.97	42.41	41.11	42.51	37.32	39.15	492.68
1973	42.33	40.99	37.65	36.32	30.94	25.17	19.17	24.99	32.91	33.54	22.92	18.55	368.39
1974	32.22	36.99	42.32	42.35	35.33	42.49	41.00	42.40	40.93	42.00	36.69	32.93	472.64
1975	33.34	26.73	35.20	42.56	35.11	40.35	38.09	40.80	41.53	43.18	43.24	41.73	456.53
1976	43.27	41.59	43.25	43.32	38.54	43.47	41.93	43.10	41.50	42.64	43.30	41.72	507.64
1977	41.23	41.76	42.95	42.89	33.49	31.25	30.07	21.80	15.22	17.81	22.62	19.28	357.41
1978	23.64	35.14	42.55	43.11	39.05	42.20	39.55	43.13	41.54	42.62	39.17	35.40	472.11
1979	34.35	40.39	42.77	42.44	32.19	36.10	35.94	38.48	33.83	26.34	25.56	24.66	413.25
1980	25.53	24.34	34.42	38.54	28.69	27.84	27.88	33.95	40.60	42.91	25.78	19.32	371.50
1981	36.26	37.50	42.16	43.05	38.72	34.25	32.63	32.95	41.98	42.08	28.07	21.61	433.36
1982	22.91	30.25	39.45	42.94	37.66	42.75	40.84	42.73	41.95	43.37	43.32	32.82	450.99
1983	42.48	41.99	43.44	43.52	39.31	43.52	42.05	43.47	42.12	43.64	43.66	33.42	502.62
1984	39.65	43.01	44.25	44.46	41.67	44.64	42.54	44.52	43.22	44.39	41.43	42.52	516.30
AVE.	32.15	33.73	37.58	38.27	33.34	35.10	30.99	27.72	27.80	31.77	32.15	29.24	399.85

APPENDIX E

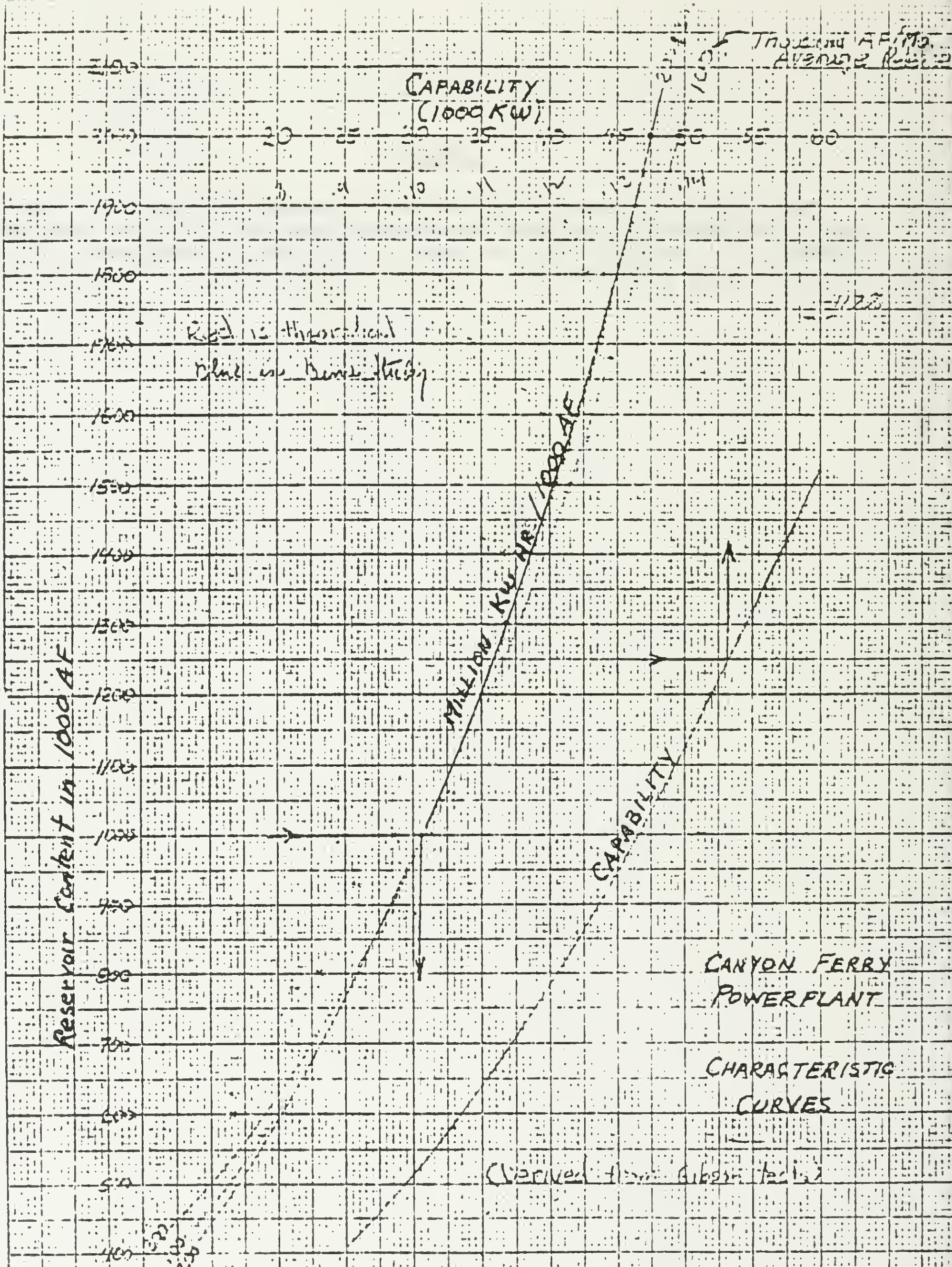
Table E-1 lists the month-end storage goals that were targeted in the operation of Canyon Ferry Reservoir.

TABLE E-1

Month	Month-End Storage Goal (Acre-ft)
Oct	1,830,000
Nov	1,850,000
Dec	1,780,000
Jan	1,680,000
Feb	1,600,000
Mar	1,500,000
Apr	1,500,000
May	1,680,000
June	1,927,000
July	1,883,500
Aug	1,800,000
Sept	1,760,000

APPENDIX F

This appendix contains the Bureau of Reclamation's Canyon Ferry power plant characteristic curves (and corresponding equations). It also contains information on reservoir surface area-volume-elevation relationships and reservoir storage allocations.


Thousand AF/Mo.
Average Release
CAPABILITY
(1000 KW)
20
25
30
35
40
45
50
55
60
1900
1800
1400
1300
1200
1100
1000
900
800
700
600
500
400
Reservoir Content in 1000 AF
MILLION KW HR / 1000 AF
CAPABILITY
CANYON FERRY
POWERPLANT
CHARACTERISTIC
CURVES
.070
.110
.120
.130
Million KW-HRS per 1000 AF released.

Canyon Ferry Powerplant Characteristics

1- Powerplant Capability =
$.6795(\text{storage in } 1000\,af)^{.6114}$

2- Powerplant Generation per 1000 af (million kwhrs)
$.00642(\text{storage in } 1000\,af)^{.40117}$
(for discharges greater then 3300 ft^3/s)

$.004936(\text{Storage in } 1000\,af)^{.43936}$
(for discharges less then 3300 ft^3/s)

With Unity Power Factor (No reactive or "Voltage raising" power), Canyon Ferry starts to lose capability at elevation 3750.

If significant amounts of reactive power are required, loss of capability starts at about 3763.

FIRST USED JULY 1 1964

CANYON FERRY RESERVOIR

Area in Acres

March 1964

ELEVATION FEET	0	1	2	3	4	5	6	7	8	9
3630							67	133	200	267
3640	333	400	467	533	600	667	733	800	867	933
3650	1000	1078	1158	1240	1323	1408	1494	1582	1672	1764
3660	1857	1952	2049	2148	2249	2351	2455	2561	2669	2779
3670	2891	3005	3121	3239	3359	3481	3605	3732	3860	3990
3680	4123	4263	4409	4553	4697	4843	4989	5135	5281	5427
3690	5573	5714	5855	5996	6137	6278	6420	6562	6706	6850
3700	6995	7151	7307	7465	7622	7778	7934	8089	8242	8393
3710	8541	8661	8778	8896	9014	9133	9256	9382	9514	9652
3720	9798	9988	10186	10391	10601	10816	11035	11256	11479	11702
3730	11925	12113	12304	12494	12685	12878	13074	13274	13478	13688
3740	13805	14138	14378	14627	14884	15150	15425	15709	16003	16307
3750	16622	16972	17332	17701	18076	18458	18845	19235	19628	20023
3760	20418	20782	21145	21509	21874	22241	22610	22982	23359	23740
3770	24126	24546	24972	25401	25833	26266	26701	27135	27567	27997
3780	28426	28837	29245	29647	30044	30434	30817	31192	31560	31920
3790	32270	32611	32942	33263	33574	33873	34160	34435	34697	34946
3800	35181									

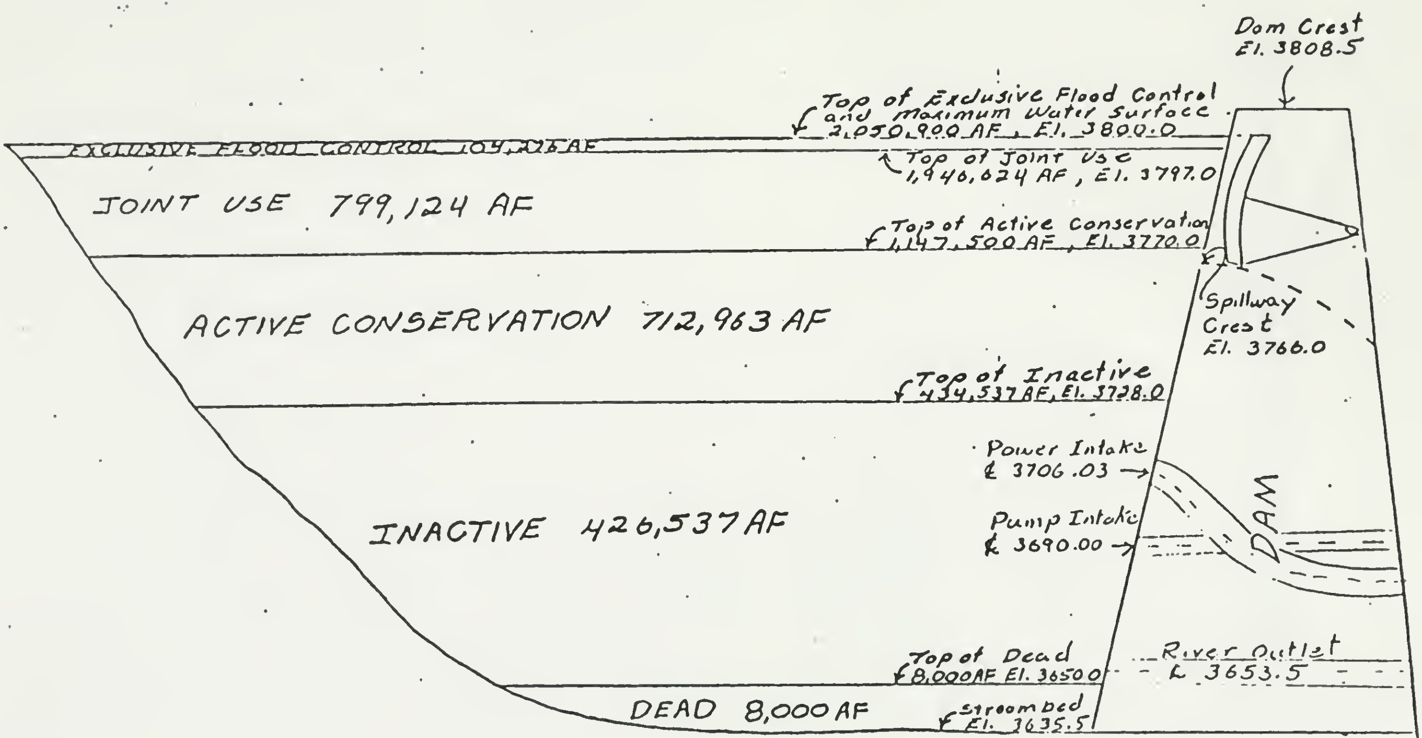
CANYON FERRY RESERVOIR

Total Capacity in Acre-Feet

March 1964

ELEVATION FEET	0	1	2	3	4	5	6	7	8	9
3630							533	1067	1600	2133
3640	2667	3200	3733	4267	4800	5333	5867	6400	6933	7467
3650	8000	8739	9527	10368	11267	12227	13253	14349	15519	16768
3660	18098	19516	21024	22626	24328	26133	28045	30069	32208	34464
3670	36849	39360	42002	44781	47701	50765	53978	57344	60867	64551
3680	68400	72606	76954	81446	86080	90858	95779	100844	106052	111404
3690	116900	122537	128318	134244	140315	146531	152893	159400	166054	172853
3700	179800	186908	194163	201564	209110	216800	224634	232612	240733	248996
3710	257400	265888	274519	283298	292226	301306	310542	319937	329493	339213
3720	349100	359149	369371	379770	390350	401112	412062	423203	434537	446068
3730	457800	469741	481889	494247	506818	519606	532614	545844	559299	572984
3740	586900	600952	615249	629798	644610	659694	675058	690711	706663	722923
3750	739500	756470	773772	791409	809388	827712	846388	865419	884812	904570
3760	924700	945250	966178	987487	1009179	1031256	1053721	1076575	1099822	1123462
3770	1147500	1171960	1196819	1222080	1247742	1273806	1300274	1327147	1354425	1382109
3780	1410200	1438831	1467863	1497289	1527102	1557294	1587854	1618788	1650077	1681716
3790	1713700	1746021	1778671	1811645	1844954	1878531	1912430	1946624	1981105	2015866
3800	2050900									

CANYON FERRY RESERVOIR ALLOCATIONS



APPENDIX G

This appendix contains the Bureau of Reclamation's general operating principles for Canyon Ferry.

GENERAL OPERATING PRINCIPALS AT CANYON FERRY

1. The top 3 feet between elevation 3797 and 3800 are used exclusively for downstream flood control and when storage rises into this pool operation of the reservoir is directed by the Corps of Engineers. This storage is generally evacuated as fast as downstream conditions permit.

2. As soon as the storage has peaked, usually in June or July, power releases are adjusted so that the pool will be drawn to about elevation 3783 by the following March 1. Inflows are reestimated each month and releases adjusted accordingly. Releases to meet this schedule are limited to powerplant capacity. Water is not spilled to provide this drawdown.

3. Most of the stored water that will be released from Hebgen is released in October and November and restorage of this water in Canyon Ferry may cause its pool to rise slightly in these months. However, MPC will try to limit the Hebgen drawdown during these months in an effort to maintain Canyon Ferry pool below elevation 3794 after December 1. Storage below elevation 3794 prior to winter freeze-up is desired to prevent ice-jam problems at the head end of the lake.

4. Beginning about January 5, and monthly thereafter through June 5, forecasts are made, from the snow cover and precipitation, of the estimated April-July inflow. When these forecasts become available, operational procedures are changed. Based on forecasts made about January 5, February 5, and March 5, releases are set based on the most probable April-July inflow forecast to allow the reservoir to fill to elevation 3797 near the end of June. There are two limitations on release rates during these 3 months, (a) release no more than powerplant capacity, and (b) release no less than required to produce critical period energy at Canyon Ferry and The Montana Power Company (MPC) Missouri River powerplants. In a dry year item (b) may result in the reservoir pool not reaching elevation 3797, the top of the joint use pool.

5. With forecasts made on or after April 5, operations are still based on reaching elevation 3797. However, if the forecasts show that releases in excess of powerplant capacity must be made, the amount of water scheduled for spilling is based on the assured runoff (90 percent chance that inflow will exceed this) rather than the most probable runoff. Water forecast as surplus in April and May is scheduled for release by June 5 and that forecast as surplus on June 5 usually scheduled for release by June 15. Spilling of additional water is made only to the extent that current inflows and reservoir contents indicate that additional spills are required. Releases are limited to 15,000 c.f.s. or full downstream channel capacity as long as space is available.

In years of unusually heavy snowpack it may be desirably to begin releasing assured spills prior to April. If this assured spill can be beneficially used by MPC during March and early April it may be released as long as it does not result in a loss of powerplant capability at Canyon Ferry or jeopardize the refill of Canyon Ferry Reservoir.

6. Depending on when the spring runoff starts, the release of water based on inflow forecasts may draw the pool as low as elevation 3770. In a series of dry years the pool may be drawn as low as elevation 3728 to meet firm power generation requirements, and satisfy MPC prior water rights. If storage is drawn below elevation 3728, the powerplant will become inoperable. Below elevation 3783 total powerplant generating capability is limited by reduced head on the power turbines.

7. The operation of Canyon Ferry is closely coordinated with MPC. During low runoff years it may be determined beneficial to the Bureau and MPC to generate more than critical period energy. This can be done if both the Bureau and MPC agree but it will be at the risk of possibly having less than critical period energy, at a later date, if dry conditions should persist.

APPENDIX H

Table H-1 lists irrigated area inflows ("natural" inflows) as simulated for the period from 1955 through 1984.

TABLE H-1

Inflows to Canyon Ferry Aggregate Irrigated Area (Acre-Ft)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1955	95534.4	98931.7	63202.8	75814.5	71189.9	123054.4	239718.8	516033.6	979906.8	820540.5	534402.6	158225.5
1956	59899.4	76387.7	107638.8	119494.5	88981.9	253406.4	426035.8	966614.5	1149392.8	659933.6	549719.6	179145.5
1957	82947.4	135109.7	74883.8	41964.5	103242.9	172379.4	261870.8	748526.6	1267152.8	731240.6	529606.6	191857.5
1958	136805.4	136498.7	108421.8	98174.5	130190.9	167647.4	294565.8	749664.6	997704.8	730939.6	553944.6	170872.5
1959	111735.4	106996.7	104375.8	85979.5	89053.9	182937.4	282902.8	517098.6	1244699.8	783049.6	522823.6	163116.5
1960	264357.4	299003.7	335725.8	121910.5	151792.9	294622.4	439600.8	646123.6	906891.8	581248.6	525025.6	154750.5
1961	36786.4	55443.7	74466.8	85610.5	117938.9	128513.4	151624.8	362733.6	772298.9	555463.6	489052.6	185075.5
1962	160927.4	159391.7	57178.8	60611.5	125451.9	173881.4	383946.8	655114.6	1159811.8	752303.6	593296.6	225856.5
1963	140826.4	141655.7	111180.8	65189.5	204034.9	160758.4	234916.8	659670.6	1367988.8	759662.6	533474.6	227403.5
1964	108811.4	129139.7	75912.8	98049.5	117533.9	150862.4	262428.8	705847.6	1623187.8	944178.5	583142.6	236872.5
1965	109747.4	128655.7	98895.8	156763.5	137009.9	178066.4	433834.8	851337.6	1586975.8	1129097.4	674039.6	321855.5
1966	256651.4	242510.7	131884.8	131488.5	141712.9	192495.4	280524.8	437349.6	723894.9	601956.6	494850.6	136980.5
1967	115920.4	130958.7	72243.8	100873.5	102836.9	131561.4	219459.8	726359.6	1690905.8	955573.5	565858.6	213007.5
1968	160576.4	140457.7	92551.8	119492.5	185052.9	248525.4	306099.8	614463.6	1484693.8	828555.5	655908.6	320521.5
1969	188499.4	171907.7	108064.8	130100.5	167168.9	262657.4	618930.8	1073813.5	1140113.8	959869.5	608434.6	215841.5
1970	182479.4	137896.7	115946.8	127856.5	145236.9	184746.4	288125.8	889533.5	1625625.8	966212.5	602485.6	297417.5
1971	179500.4	158488.7	121131.8	148151.5	212635.9	180731.4	414728.8	957950.5	1550810.8	996734.5	625013.6	300886.5
1972	197092.4	171766.7	103062.8	143286.5	175183.9	285038.4	421087.8	767976.6	1432667.8	778257.6	605853.6	247763.5
1973	206174.4	189841.7	91349.8	118336.5	136281.9	197000.4	280520.8	591423.6	904118.8	680039.6	540293.6	244109.5
1974	149498.4	158770.7	113923.8	122481.5	141995.9	204287.4	404187.8	722193.6	1513273.8	812715.5	611476.6	216436.5
1975	146031.4	93712.7	114631.8	102902.5	108179.9	186843.4	295737.8	798479.6	1656400.8	1399263.4	795264.5	301924.5
1976	258317.4	228705.7	236458.8	196125.5	177418.9	258539.4	540640.8	1294450.5	1397127.8	885939.5	669939.6	332544.5
1977	262483.4	194625.7	142527.8	109160.5	132131.9	153943.4	285846.8	378509.6	791254.9	594058.6	518461.6	205517.5
1978	143230.4	96336.7	101657.8	113460.5	135670.9	288388.4	443639.8	782959.6	1187552.8	922177.5	588712.6	299510.5
1979	169577.4	104094.7	94610.8	82358.5	123329.9	265340.4	388478.8	776747.6	948057.8	633299.6	555092.6	162357.5
1980	48279.4	79208.7	82194.8	62503.5	133627.9	176231.4	345741.8	866348.6	1300004.8	788398.6	557048.6	279588.5
1981	147777.4	142646.7	133429.8	128681.5	126173.9	172930.4	277942.8	1025880.5	1579380.8	749655.6	550298.6	148510.5
1982	139212.4	116911.7	113800.8	87548.5	172200.9	219038.4	361946.8	910901.5	1614384.8	1133157.4	620913.6	300323.5
1983	213324.4	180800.7	146756.8	181995.5	162266.9	247549.4	341817.8	671849.6	1247046.8	1092468.4	675027.6	312426.5
1984	261001.4	256252.7	145056.8	216089.5	195628.9	243784.4	393961.8	969149.5	1660304.8	1084746.4	783542.5	374483.5